Saskatchewan
Research Council

# AN EVALUATION OF THE EFFECTS OF LAND APPLICATION OF OIL AND GAS DRILLING WASTES ON SOILS AND CROPS IN THE KINDERSLEY AND ESTEVAN REGIONS OF SASKATCHEWAN - A SUMMARY REPORT

by

Zoheir M. Abouguendia
Robert C. Godwin
Lawrence A. Baschak

SRC Technical Report No. 218

Publication E-902-10-B-87 June, 1987

# AN EVALUATION OF THE EFFECTS OF LAND APPLICATION OF OIL AND GAS DRILLING WASTES ON SOILS AND CROPS IN THE KINDERSLEY AND ESTEVAN REGIONS OF SASKATCHEWAN - A SUMMARY REPORT

by
Zoheir M. Abouguendia
Robert C. Godwin
Lawrence A. Baschak

Saskatchewan Research Council

SRC Technical Report No. 218

SRC Publication No. E-902-10-B-87

June, 1987

ACKNOWLEDGEMENTS

This study was funded jointly by the Saskatchewan Energy and Mines (SEM) and the Saskatchewan Research Council (SRC).

The assistance and cooperation of the SEM field staff, the oil and gas industry, the Saskatchewan Surface Rights Associations, and the drilling fluids and drilling waste disposal firms are gratefully acknowledged.

The authors wish to thank Mr. Les Bernier (Engineering Services Branch, SEM) for his cooperation and guidance throughout the project. Also, thanks are due to the members of the Project Review Committee: Roy Button (Saskatchewan Agriculture), Paul Hanley (SEM), Graham G.P. Mutch and B.J. Ryma (Saskatchewan Environment) and J. Reud French (SaskOil) for their feedback.

Dr. E. de Jong and Dr. P. Huang (Soil Science Department, University of Saskatchewan) reviewed the report and provided useful comments and suggestions. Thanks are due to Mr. D. Tomasiewicz (Saskatchewan Soil Testing Laboratory) for his cooperation.

Thanks are also due to the following SRC staff for their assistance and cooperation:

* Dr. Wo Yuen (Analytical Services)

* Mrs. D. Collins, Miss Darlene Diduck, Mrs. B. Hoyseth, and Mrs. G. Calderon (Departmental Services)

* Mr. C. Sardinha and Mrs. J. Mamer (Graphic Services)

* Mrs. C. Rickard, Miss C. Beaulieu, Mr. R. Bouvier, Mr. C. Gunn, Mr. D. Hill, Mr. John Polson and Mr. R. Begrand (Environment Division).

TABLE OF CONTENTS


| | Page |
|---|---|
| ACKNOWLEDGEMENTS | i |
| LIST OF TABLES | iii |
| LIST OF FIGURES | v |
| 1 BACKGROUND AND OBJECTIVES | 1 |
| 2 METHODS | 3 |
| 2.1 Growth Room Experiments | 3 |
| 2.2 Case Studies | 8 |
| 3 RESULTS AND DISCUSSIONS | 19 |
| 3.1 Growth Room Experiments | 19 |
| 3.1.1 Germination | 19 |
| 3.1.2 Seedling Emergence | 19 |
| 3.1.3 Yield Experiments | 24 |
| 3.1.3.1 Soils | 24 |
| 3.1.3.2 Plants | 33 |
| 3.2 Field Investigations | 45 |
| 3.2.1 Drilling Waste Characteristics | 45 |
| 3.2.2 Soils | 46 |
| 3.2.3 Crops | 52 |
| 3.2.4 Grasslands | 57 |
| 4 CONCLUSIONS | 58 |
| 4.1 Growth Room Experiments | 58 |
| 4.1.1 Soil Characteristics | 58 |
| 4.1.2 Seed Germination and Seedling Emergence | 59 |
| 4.1.3 Yield | 59 |
| 4.1.4 Trace Element Uptake by Plants | 60 |
| 4.2 Field Investigations | 61 |
| 4.2.1 Soil Characteristics | 61 |
| 4.2.2 Crops | 62 |
| 4.2.3 Trace Element Uptake by Plants | 62 |
| 4.2.4 Grasslands | 62 |
| 5 RECOMMENDATIONS | 64 |
| 6 LITERATURE CITED | 66 |

# LIST OF TABLES


| Table | | Page |
|---|---|---|
| 2.1 | Characteristics of the Drilling Waste Samples Used in the Growth Room Experiments | 5 |
| 2.2 | Concentration of the Trace Constituents in the Drilling Waste Samples Used in the Growth Room Experiments | 6 |
| 2.3 | Characteristics of the Soils Used in the Growth Room Experiments | 9 |
| 2.4 | Trace Element Concentration in the Growth Room Experimental Soils | 10 |
| 2.5 | Year of Drilling Waste Disposal and Estimated Waste Application Rate at the Various Sites Investigated | 12 |
| 2.6 | Mud Formulation for the Kindersley Sites | 13 |
| 2.7 | Mud Formulation for the Estevan Site Wells | 14 |
| 2.8 | Salinity Analysis of Additional Drilling Waste Samples Involved in the Field Investigations | 15 |
| 2.9 | Concentration of the Trace Constituents in Three Additional Drilling Waste Samples Collected in Connection with the Field Investigations | 16 |
| 2.10 | Sites of Field Investigations and Parameters Studied at Each Site | 17 |
| 3.1 | Effects of Drilling Waste Sample No. K13 on Seedling Emergence of Field Crops and Alfalfa | 21 |
| 3.2 | Effects of Drilling Waste Sample No. E19 on Seedling Emergence of Field Crops and Alfalfa | 22 |
| 3.3 | Range of Trace Element Loading Rates Calculated for the Various Waste Application Rates | 31 |
| 3.4 | Number of Experiments in Which Significant Elevation in Soil Trace Element Concentration Occurred | 32 |
| 3.5 | Summary of the Yield Statistical Significance Tests for the Growth Room Experiments | 35 |
| 3.6 | Summary of the Yield Data from the Growth Room Experiments | 36 |
| 3.7 | Number of Experiments in Which Trace Element Levels in the Grain Was Elevated as a Result of Drilling Waste Application | 42 |

LIST OF TABLES (Continued)


| Table | | Page |
|---|---|---|
| 3.8 | Number of Experiments in Which Trace Element Levels in the Wheat Straw Was Elevated . . . . . | 44 |
| 3.9 | Changes in Soil Salinity in Treated Sites as Compared to the Control Soils . . . . . | 47 |
| 3.10 | Summary of the Statistical Significance Test Results of the EM38 Soil Electrical Conductivity Data . . . . . | 48 |
| 3.11 | Changes in Soil Trace Element Concentrations in Treated as Compared to the Control Soils . . . . . | 51 |
| 3.12 | Summary of the Plant Density and Height Statistical Significance Tests . . . . . | 53 |
| 3.13 | Summary of the Yield Statistical Significance Tests . . . . | 56 |

# LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 3.1 | Summary of the Germination Data . . . . . | 20 |
| 3.2 | Summary of Seedling Emergence Data for a Kindersley Site and an Estevan Site . . . . . | 23 |
| 3.3 | Effect of Waste Application on Soil pH and Electrical Conductivity Under Growth Room Conditions . . . . . | 25 |
| 3.4 | Effects of Waste Application on Extractable Sodium and Magnesium Under Growth Room Conditions . . . . . | 27 |
| 3.5 | Effects of Waste Application on Available Soil Nitrogen and Phosphorous Under Growth Room Conditions . . . . . | 30 |
| 3.6 | Effects of Waste Application on Grain and Straw Yield of Wheat Under Growth Room Conditions . . . . . | 34 |
| 3.7 | Relationship Between Grain Yield and Waste Application Rate Under Growth Room Conditions . . . . . | 38 |
| 3.8 | Relationship Between Straw Yield and Waste Application Rate Under Growth Room Conditions . . . . . | 39 |
| 3.9 | Relationship Between Grain Yield and Electrical Conductivity of the Soil at the End of the Growth Room Experiments . . . . . | 41 |

# 1 BACKGROUND AND OBJECTIVES

A preliminary study, commissioned by the Saskatchewan Department of Energy and Mines, provided an overview of the potential effects of oil and gas drilling waste disposal on Saskatchewan soils and crops (Abouguendia et al. 1985). That study was based on available literature, mainly from United States sources. The main conclusions from that study included:

(1) The physical and chemical characteristics of drilling wastes are highly variable depending on such factors as type of drilling fluids used, sump treatment, and age of sump.

(2) Land application of drilling wastes can affect seed germination; plant growth, yield and cover; and soil physical and chemical properties. The magnitude and direction (positive or negative) of effects vary with such factors as drilling waste characteristics, rate of waste application, chemical and physical properties of the receiving soil and climatic conditions.

(3) The apparent beneficial effects associated with some cases of land application of freshwater drilling muds may be related to improvement in the physical properties of the soil and/or increased nutrient availability.

(4) The drilling waste parameters of concern appear to be salinity and specific ion concentrations, sodicity, trace element content and possibly organic compounds. However, under field conditions salinity and/or sodicity account for most of the detrimental effects observed.

The overview study recommended that further investigations be carried out under the Saskatchewan conditions to provide quantitative data necessary for the formulation of environmental protection guidelines and

to assess the long-term effects of drilling waste disposal on agricultural land.

The study program recommended in the preliminary phase consisted of:

* Case studies to evaluate present on-site disposal practices and assess long-term effects of drilling waste disposal on agricultural production.

* A comprehensive field experimentation program supplemented by growth room studies to evaluate the effects of controlled applications of drilling wastes on soils and crops.

* Development of a terrestrial toxicity test for possible use in sump pit evaluation.

The objectives of the present study are:

(1) To assess the soil and crop conditions associated with the present on-lease and off-lease drilling waste disposal practices in the Kindersley and Estevan areas; and

(2) To evaluate the effects of soil application of drilling wastes on soils and crops under controlled growth room conditions.

The present study dealt only with three wastes generated from the use of the freshwater-based drilling fluids, i.e. gel chemical type. This type is the most common type used in the oil and gas fields of Saskatchewan (Abouguendia et al. 1985).

# 2 METHODS

The study consisted of two main parts:

(1) An assessment of the effects of soil application of drilling wastes on soils and crops under controlled growth room conditions (referred to here as growth room studies or experiments).

(2) An evaluation of the soil and crop conditions associated with the present on-lease and off-lease drilling waste disposal practices in the Kindersley and Estevan areas (referred to here as case studies or field investigations).

## 2.1 Growth Room Experiments

This portion of the study involved evaluation of the phytotoxicity of a number of sump fluid (waste) samples collected from the two study regions. Each waste sample is a composite of several subsamples collected from different locations and depths within the sump.

The following experiments were carried out:

Germination

Wheat (Katepwa) was used in this experiment to test the response to drilling wasted at the germination stage. Drilling wastes from the following sites were used:

Kindersley

(1) K8 (D16-23-31-23-W3)

(2) K17 (4-4-33-23-W3)

(3) K13 (4-25-32-24-W3)

Estevan

(4) E9 (13-29-2-14-W2)

(5) E19 (8-31-5-13-W2)

Sterilized, 9 cm Petri dishes were used in the tests. Twenty-five seeds were placed on filter paper and 10 mL of waste were added. Completely randomized experimental design with four replicates was used. Two control treatments were included: a medium-textured, dark brown soil; and deionized water. Laboratory temperature was 25±2°C. Germination counts were made after three, five, and six days.

Characteristics of the drilling waste samples used in this experiment are shown in Tables 2.1 and 2.2.

Seedling Emergence Experiments

These experiments aimed at evaluating the effect on seedling emergence of the main field crops of different waste application rates. Two varieties of wheat, Katepwa and Columbus, were used. Also, barley (Melvin) and alfalfa were included in these experiments. Drilling waste application rates were as follows:

(1) 0 barrels per acre (control).

(2) 100 barrels per acre (low rate)

(3) 200 barrels per acre (moderate rate)

(4) 400 barrels per acre (high rate)

(5) 2000 barrels per acre (very high rate)

Sump pit wastes from the following sites were used in the seedling emergence experiments:

Kindersley

(1) K13 (4-25-32-24-W3)

(2) K8 (D16-23-31-23-W3)

Estevan

(3) E19-8-31-5-13-W2)

Table 2.1 Characteristics of the Drilling Waste Samples Used in the Growth Room Experiments.

| Waste Source (Site No.) | Water Soluble Ions* | | | | | | Total Dissolved Solids* | pH |
|---|---|---|---|---|---|---|---|---|
| | Ca | Cl | K | Mg | Na | $SO_4$ | | |
| Kindersley | | | | | | | | |
| K8 | 20 | 650 | 15 | 3 | 1300 | 1900 | NA | 9.7 |
| K17 | 21 | 96 | 13 | 3 | 530 | 350 | 1830 | 10.4 |
| K13 | 9 | 100 | 5 | 0.4 | 410 | 240 | 1570 | 11.3 |
| Estevan | | | | | | | | |
| E9 | 770 | 1800 | 31 | 16 | 4000 | 7900 | 15900 | 8.1 |
| E19 | 810 | 2300 | 28 | 0.6 | 4600 | 8200 | 17600 | 10.4 |

*Concentration in mg/L.

n/a no data.

Table 2.2 Concentration (ug/g) of the Trace Constituents in the Drilling Waste Samples Used in the Growth Room Experiments.

| Waste Source (Site No.) | Al | B | Ba | Co | Cr | Cu | Mn | Mo | Ni | Pb | Zn | P | Ether Extract |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kindersley | | | | | | | | | | | | | |
| K8 | 38,000 | <5 | 2700 | 10 | 50 | 45 | 450 | 30 | 25 | 40 | 76 | 620 | 2600 |
| K17 | 53,000 | 10 | 700 | 14 | 70 | 37 | 280 | 45 | 44 | 90 | 140 | 1300 | 3700 |
| K13 | 39,000 | 9 | 710 | 13 | 50 | 20 | 350 | 33 | 34 | 56 | 230 | 1100 | 120 |
| Estevan | | | | | | | | | | | | | |
| E9 | 40,000 | 21 | 180 | 8.5 | 68 | 28 | 300 | 31 | 25 | 69 | 69 | 490 | 890 |
| E19 | 36,000 | <5 | 22 | 7.2 | 39 | 22 | 260 | 27 | 19 | 70 | 140 | 450 | 480 |

(4) E9 (13-29-2-14-W2)

Greenhouse trays (16 cm wide x 24 cm long x 12 cm deep) were used. Six replicates were employed. The number of seedlings emerged after four, six, and seven days was noted.

Growth room conditions are as indicated in the yield experiment, below. Flats were watered as needed.

Characteristics of the drilling waste samples used here are given in Tables 2.1 and 2.2.

Yield Experiments

The objectives of the yield experiments were to assess the effects of different drilling waste application rates on yield, to evaluate changes in soil properties and to investigate trace element levels in soil and possible uptake by plants.

Plastic pots, 12.5 cm in diameter, were used. Completely randomized statistical design with eight replicates was used. In these experiments, wheat (Katepwa) was used. Drilling waste was applied at the following rates:

(1) 0 barrels/acre (control)

(2) 100 barrels/acre (low rate)

(3) 200 barrels/acre (moderate rate)

(4) 2000 barrels/acre (very high rate)

Growth room temperature was kept around 25±2°C during the day (16 hours) and 17±2°C during the night (8 hours). The light level was 500 microeinsteins.$m^{-2}.s^{-1}$.

Pots were watered when soil moisture was around 50% of the field capacity.

The plant material produced was sorted into grain and straw, air-dried, weighed and then composited for trace element analysis. Four samples were analyzed for each treatment in each experiment, unless material produced was insufficient as in the case of the very high application rate.

The soil parameters evaluated at the end of the experiment included: saturation percentage, pH, electrical conductivity, water soluble ions, extractable cations (Ca, Mg, Na, and K), available nutrients (N, P, and K) and total concentration of trace elements (including Al, B, Ba, Co, Cr, Cu, Mo, Ni, Pb and Zn).

Drilling wastes from the following sites were used in the yield experiments carried out under growth room conditions:

Kindersley

(1) K8 (D16-23-31-23-W3)

(2) K17 (4-4-33-23-W3)

(3) K13 (4-25-32-24-W3)

Estevan

(4) E9 (13-29-2-14-W2)

(5) E19 (8-21-5-13-W2)

The physical and chemical characteristics of the drilling wastes used in this experiment are given in Tables 2.1 and 2.2.

The soils used were Weyburn loam from the Estevan region and Elstow clay loam from the Kindersley region. The properties of the soils used are presented in Tables 2.3 and 2.4.

## 2.2 Case Studies

An initial list of potential study sites was prepared in consulta-

Table 2.3 Characteristics of the Soils Used in the Growth Room Experiments. (Means followed by standard deviation.)

| | Kindersley (Elstow Clay Loam) | Estevan (Weyburn Loam) |
|---|---|---|
| Moisture Saturation (%) | 50 (0) | 46 (1.5) |
| pH | 5.85 (0.06) | 6.68 (0.25) |
| Electrical Conductivity (mS/cm) | 2.43 (0.75) | 2.23 (0.19) |
| Water Soluble Ions (mg/L) | | |
| $Na^+$ | 162 (63) | 203 (19) |
| $Ca^+$ | 220 (85) | 179 (17) |
| $Mg^+$ | 116 (42) | 66 (6) |
| $K^+$ | 33 (6) | 45 (3) |
| $Cl^-$ | 208 (65) | 183 (22) |
| $SO_4^{--}$ | 980 (387) | 747 (80) |
| SAR | 2.15 (0.4) | 3.28 (0.26) |
| Available Nutrients (ppm) | | |
| $NO_3$-N | 5.1 (0.6) | 7.9 (1.9) |
| P | 12.3 (0.5) | 15.9 (0.6) |
| K | 268 (19) | 343 (12.6) |

Table 2.4 Trace Element Concentration (ug/g) in the Growth Room Experimental Soils. (Means followed by standard deviation.)

| | Kindersley (Elstow Clay Loam) | Estevan (Weyburn Loam) |
|---|---|---|
| Available B | 0.18 (0.02) | 0.37 (0.05) |
| Total Al | 34500 (1000) | 23000 (1414) |
| Total B | 16.5 (1.9) | 12.8 (1.9) |
| Total Ba | 310 (20) | 225 (17) |
| Total Co | 12 (0.0) | 9.7 (0.7) |
| Total Cr | 46.5 (7.7) | 31.5 (2.7) |
| Total Cu | 19.8 (1.0) | 15 (1.2) |
| Total Mo | 11.8 (1.3) | 6.5 (0.6) |
| Total Ni | 21.8 (2.1) | 16.0 (1.2) |
| Total Pb | 10.0 (1.4) | 10.3 (1.5) |
| Total Zn | 99.8 (23.7) | 78.5 (7.0) |
| Total P | 512.5 (20.6) | 655.0 (52.6) |

tion with the Saskatchewan Energy and Mines, drilling waste disposal firms, drilling mud firms and representatives of the Surface Rights Associations. Candidate sites were selected from the list of identified sites on the basis of the following criteria:

* Availability of waste chemistry or mud formulation data.

* Availability of information on disposal location and rates.

* Representativeness of the main soil types in the two study regions, Kindersley and Estevan.

* Availability of an appropriate control site for comparison purposes.

General information on the study sites is given in Table 2.5, while available drilling fluids formulation data are given in Tables 2.6 and 2.7. Characteristics of the drilling wastes sampled in connection with the field study are given in Tables 2.1, 2.2, 2.8 and 2.9.

A detailed evaluation was carried out at a number of sites in each of the two study regions (Table 2.10). The detailed evaluation involved:

Soils

* Sampling of soils for detailed chemical analysis. The soil parameters determined included: saturation percentage, pH, electrical conductivity, water soluble ions, extractable cations, available nutrients and total concentration of trace elements (Al, B, Ba, Co, Cr, Cu, Mo, Ni, Pb and Zn). In addition, soil electrical conductivity was measured using an EM38 terrain conductivity meter. For on-lease disposal sites, a salinity map was prepared on the basis of the EM38 data.

Table 2.5 Year of Drilling Waste Disposal and Estimated Waste Application Rate (barrels/acre) at the Various Sites Investigated.

| Region Site | Year | Estimated Disposal Rate | Notes |
|---|---|---|---|
| Kindersley | | | |
| K1 | 1984 | 1500 | On-lease |
| K3 | 1985 | 100 | Off-lease |
| K8 | 1985 | 100 | Off-lease |
| K16 | 1985 | 110 | Off-lease |
| K17 | 1985 | 150 | Off-lease |
| K21 | 1985 | 100 | Off-lease |
| K22 | 1985 | * | Off-lease |
| K24 | 1985 | 100 | Off-lease |
| K30 | 1984 | 1500 | On-lease |
| Estevan | | | |
| E1 | Before 1980 | ** | On-lease |
| E2 | Before 1980 | ** | On-lease |
| E9 | 1985 | 5000 | On-lease |
| E15 | 1977 | 5700 | On-lease |
| E16 | 1981 | 5000 | On-lease |
| E20 | 1984 | 3700 | On-lease |
| E21 | 1984 | 3900 | On-lease |
| E22 | 1985 | 3300 | On-lease |
| E28 | 1985 | 3860 | On-lease |
| E29 | 1984 | ** | On-lease |

*Unknown disposal rate.
**Unknown disposal rate but can be assumed to be around 3500 barrels/acre.

Table 2.6 Mud Formulation for the Kindersley Sites.

| Mud Components (Weight in kg)* | | | |
|---|---|---|---|
| | Site Number | | |
| Component | K1 | K24 | K30 |
| Bentonite | 720 | 2000 | 720 |
| Sawdust | | 306 | 180 |
| CMC | 69 | 46 | 69 |
| Caustic soda | 23 | 35 | 23 |
| Lignite | | 23 | |
| Lime | | 25 | |
| SAPP | 40 | | 40 |
| Detergent | 1 sac | | 1 sac |

*Amounts used for drilling the well as obtained from drilling firm invoices or from the oil companies.

Table 2.7 Mud Formulation for the Estevan Site Wells.

| Components | E9 | E15 | E16 | E20 | E21 | E22 | E28 |
|---|---|---|---|---|---|---|---|
| Gel | 5760 | 11000 | 4800 | 4200 | 4160 | 4270 | 4360 |
| Soda Ash | 720 | 545 | 1420 | 640 | 591 | 800 | 920 |
| Caustic soda | 316 | 230 | 400 | 180 | 182 | 340 | 320 |
| Lime | - | - | 20 | 45 | 68 | - | 25 |
| Dakolite | - | - | 310 | - | - | - | - |
| Sawdust | - | - | 360 | 560 | 554 | 400 | - |
| Benex | - | 22 | - | - | - | - | - |
| Starch | - | 2636 | - | - | - | - | - |
| Calcium chloride | 1591 | - | 1330 | 1140 | 1136 | 1360 | 1280 |
| Staflo | 375L | - | 325 | - | - | - | 175 |
| Stayflo | - | - | - | - | 50 | 25 | - |
| Preservative | - | 200 | - | - | - | - | - |
| Peltex | 75 | - | - | 75 | 50 | 150 | 225 |
| Alcomer | 120 | - | - | 40 | 60 | 80 | 60 |
| CMC | - | - | - | 300 | 250 | 200 | 580 |
| Reef floc | - | - | 0.5 | - | - | - | - |

*Amounts in kg used for drilling the well as obtained from drilling firm invoices or from the oil companies.

Table 2.8 Salinity analysis of Additional Drilling Waste Samples Involved in the Field Investigations.

| Waste Source (Site No.) | Water Soluble Ions* | | | | | | Total Dissolved Solids* | pH |
|---|---|---|---|---|---|---|---|---|
| | Ca | Cl | K | Mg | Na | $SO_4$ | | |
| Kindersley** | | | | | | | | |
| K3 | 7.5 | 30 | 12 | 1.4 | 320 | 450 | 810 | 8.49 |
| K16 | 32 | 350 | 250 | 2.1 | 400 | 270 | 1860 | 8.47 |
| K22 | 23 | 200 | 89 | 1.8 | 230 | 150 | 990 | 7.99 |
| Estevan*** | | | | | | | | |
| E16 | - | 14000 | - | - | - | - | - | 9.0 |
| E20 | - | 2600 | - | - | - | - | - | 10.0 |
| E21 | - | 1600 | - | - | - | - | - | 9.0 |
| E22 | - | 1630 | - | - | - | - | - | 9.5 |

*mg/L
**Samples collected and analyzed in this study.
***Data obtained from drilling reports.

Table 2.9 Concentration (ug/g) of the Trace Constituents in Three Additional Drilling Waste Samples Collected in Connection with the Field Investigations.

| Waste Source (Site No.) | Al | B | Ba | Co | Cr | Cu | Mn | Mo | Ni | Pb | Zn | P | Ether Extract |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kindersley | | | | | | | | | | | | | |
| K3 | 46,000 | 24 | 340 | 12 | 43 | 26 | 360 | 3.0 | 33 | 16 | 90 | 840 | 1030 |
| K16 | 54,000 | 28 | 510 | 13 | 63 | 42 | 320 | 8.5 | 50 | 140 | 130 | 730 | 295 |
| K22 | 42,000 | 12 | 310 | 12 | 53 | 21 | 470 | 1.5 | 37 | 28 | 85 | 840 | 253 |

Table 2.10 Sites of Field Investigations and Parameters Studied at Each Site.

| Site No. | Location | Crop | A* | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|---|
| Kindersley | | | | | | | | | | |
| 1 | 10-31-30-19 | Barley | x | | | | x | | | |
| 3 | 10-22-30-22 | DW | x | x | x | x | x | | x | x |
| 8 | NW24-31-23 | Barley | x | x | x | x | x | | x | x |
| 16 | SW4-33-23 | Mustard | x | x | x | x | x | | x | x |
| 17 | 12-4-33-23 | SF | x | x | x | x | | | | |
| 21 | 7-31-27 | HRSW | x | | | | x | | x | x |
| 22 | 7-10-33-24 | Grassland | | | | | | x | x | x |
| 24 | 14-31-22 | Barley | x | | | | x | | x | |
| 30 | 15-31-30-19 | Barley | x | | | | x | | x | |
| Estevan | | | | | | | | | | |
| 1 | 7-12-3-4 | HRSW | x | x | x | x | x | | x | x |
| 2 | 5-7-3-4 | HRSW | x | x | x | x | x | | x | x |
| 9 | 13-29-2-14 | SF | x | | | | | | | |
| 15 | 15-23-2-14 | HRSW | x | | | | x | | | |
| 16 | 9-14-2-14 | HRSW | x | | | | x | | | |
| 20 | D15-32-5-10 | HRSW | x | x | x | x | x | | x | x |
| 21 | B15-8-6-10 | WW | x | | | | x | | | |
| 22 | D15-14-6-11 | HRSW | x | x | x | x | x | | x | x |
| 28 | 9-30-6-9 | HRSW | x | | | | x | | | |
| 29 | 3-26-6-10 | Barley | x | | | | x | | | |

*A - EM38
B - Detailed Salinity
C - Soil Nutrients
D - Soil Trace Elements
E - Plant Density and Height
F - Species Composition
G - Yield
H - Plant Trace Elements

HRSW - Hard red spring wheat
WW - Winter wheat
SF - Summer fallow
DW - Durum wheat

Plants

* Sampling of crops for determining yield and for trace element analysis.

* Assessing plant density.

* Measuring plant height.

A general evaluation was carried out at several additional sites (Table 2.10). This involved, in general, the same parameters as above, except for the detailed chemical analysis.

In addition, a natural grassland site was also investigated. Here, species composition and yield were determined and plant samples were analyzed for trace element content.

# 3 RESULTS AND DISCUSSIONS

## 3.1 Growth Room Experiments

### 3.1.1 Germination

The germination data are summarized in Figure 3.1 for the last counting date (six days from the start of the experiment). Percentage germination of wheat was not significantly affected by any of the five drilling waste samples obtained from the Kindersley and Estevan regions.

### 3.1.2 Seedling Emergence

Seed germination and seedling emergence are critical stages in the life cycle of plants. In this study, the effect of soil applied drilling waste on seedling emergence of wheat (Katepwa and Columbus), barley and alfalfa was studied. In this growth room study, waste was applied at rates ranging from 0 to 2000 barrels per acre. Seedling emergence of the four field crops tested on the fourth day from planting was significantly reduced with the application of any of the four waste samples used. Most reductions were associated with the high (400 barrels/acre) and very high (2000 barrels/acre) application rates. (Examples are given in Tables 3.1 and 3.2 and Figure 3.2.)

The Kindersley samples had no significant effect on emergence seven days after planting, with the exception of alfalfa which showed significant reduction at the very high application rate of one of the waste samples (K8).

The reductions in seedling emergence observed on the fourth day with the Estevan samples have nearly disappeared by the seventh day, except when the wastes were applied at the very high level. In this case, all crops tested were adversely affected.

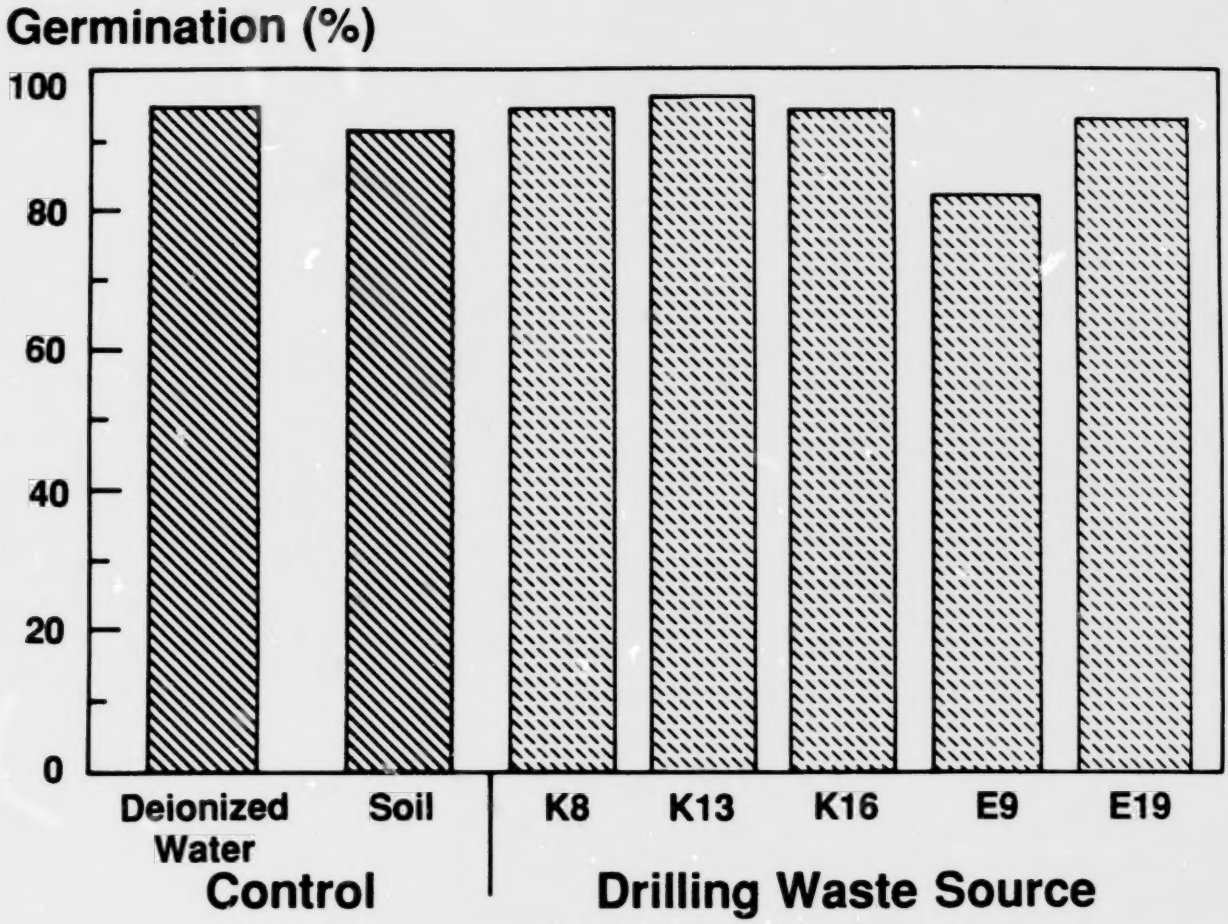


Figure 3.1 Summary of the Germination Data.

Table 3.1 Effects of Drilling Waste Sample No. K13 on Seedling Emergence of Field Crops and Alfalfa.

| Crop Treatment[1] | Emergence % Day 4 | Day 7 |
|---|---|---|
| Katepwa Wheat | | |
| 1 | 61 | 79 |
| 2 | 69 | 86 |
| 3 | 60 | 84 |
| 4 | 39 | 81 |
| 5 | 29* | 79 |
| Columbus Wheat | | |
| 1 | 52 | 66 |
| 2 | 44 | 64 |
| 3 | 44 | 70 |
| 4 | 19** | 64 |
| 5 | 13** | 66 |
| Barley | | |
| 1 | 84 | 89 |
| 2 | 76 | 87 |
| 3 | 69 | 81 |
| 4 | 46** | 84 |
| 5 | 37** | 84 |
| Alfalfa | | |
| 1 | 45 | 59 |
| 2 | 46 | 48 |
| 3 | 46 | 49 |
| 4 | 36 | 48 |
| 5 | 16** | 42 |

[1]Treatments
1 0 barrels/acre (control)
2 100 barrels/acre
3 200 barrels/acre
4 400 barrels/acre
5 2000 barrels/acre

*Significantly different from the control at the 0.05 level.
**Significantly different from the control at the 0.01 level.

Table 3.2 Effects of Drilling Waste Sample No. E19 on Seedling Emergence of Field Crops and Alfalfa.

| Crop Treatment[1] | Emergence % Day 4 | Day 7 |
|---|---|---|
| Katepwa Wheat | | |
| 1 | 46 | 68 |
| 2 | 21 | 89 |
| 3 | 23 | 80 |
| 4 | 33 | 85 |
| 5 | 0** | 5** |
| Columbus Wheat | | |
| 1 | 33 | 50 |
| 2 | 15 | 79 |
| 3 | 14 | 80 |
| 4 | 9 | 69 |
| 5 | 0** | 1** |
| Barley | | |
| 1 | 57 | 75 |
| 2 | 26 | 88 |
| 3 | 33 | 89 |
| 4 | 38 | 90 |
| 5 | 0** | 29** |
| Alfalfa | | |
| 1 | 25 | 43 |
| 2 | 23 | 48 |
| 3 | 18 | 39 |
| 4 | 18 | 34 |
| 5 | 0** | 0** |

[1]Treatments
1 0 barrels/acre (control)
2 100 barrels/acre
3 200 barrels/acre
4 400 barrels/acre
5 2000 barrels/acre

*Significantly different from the control at the 0.05 level.
**Significantly different from the control at the 0.01 level.

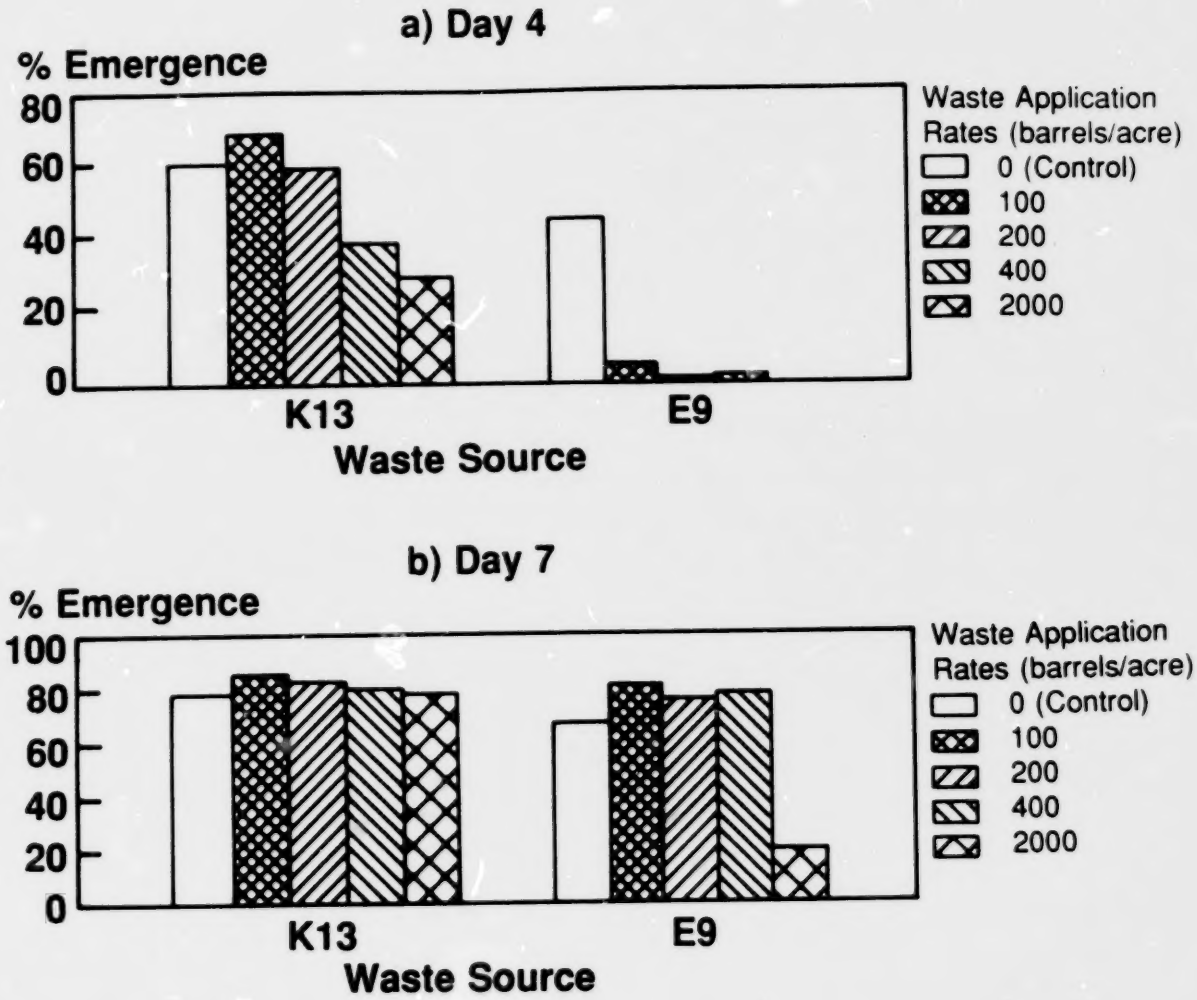


Figure 3.2 Summary of Seedling Emergence Data for a Kindersley Site and an Estevan Site.

The effect of the waste treatments on seedlings emergence appears to be related to the changes in soil characteristics as discussed in Section 3.1.3.1. In general, high salinity and sodicity are the likely causes of reduction in seedling emergence.

### 3.1.3 Yield Experiments

#### 3.1.3.1 Soils

Electrical Conductivity

Soils may be classified according to the degree of salinity as follows:

| Class | Electrical Conductivity (mS/cm) |
|---|---|
| Nonsaline | 0-2 |
| Slightly Saline | 2-4 |
| Moderately Saline | 4-8 |
| Severely Saline | 8-16 |
| Very Severely Saline | >16 |

The soils used in the growth room experiment were slightly saline (electrical conductivity of 2.2 to 2.4 mS/cm). The changes in soil salinity as a result of waste application appear to be strongly influenced by the rate of application and the water-soluble ion concentration in the waste (Figure 3.3). The low and moderate application rates (100 and 200 barrels/acre, respectively) did not result in any statistically significant increase in soil salinity. The very high application rate (2000 barrels/acre), however, resulted in significant increase in soil electrical conductivity. The three Kindersley waste samples (K8, K17, and K13) which contained low levels of soluble salts (<4000 mg/L) when applied at the high rate changed soil salinity from slightly saline to

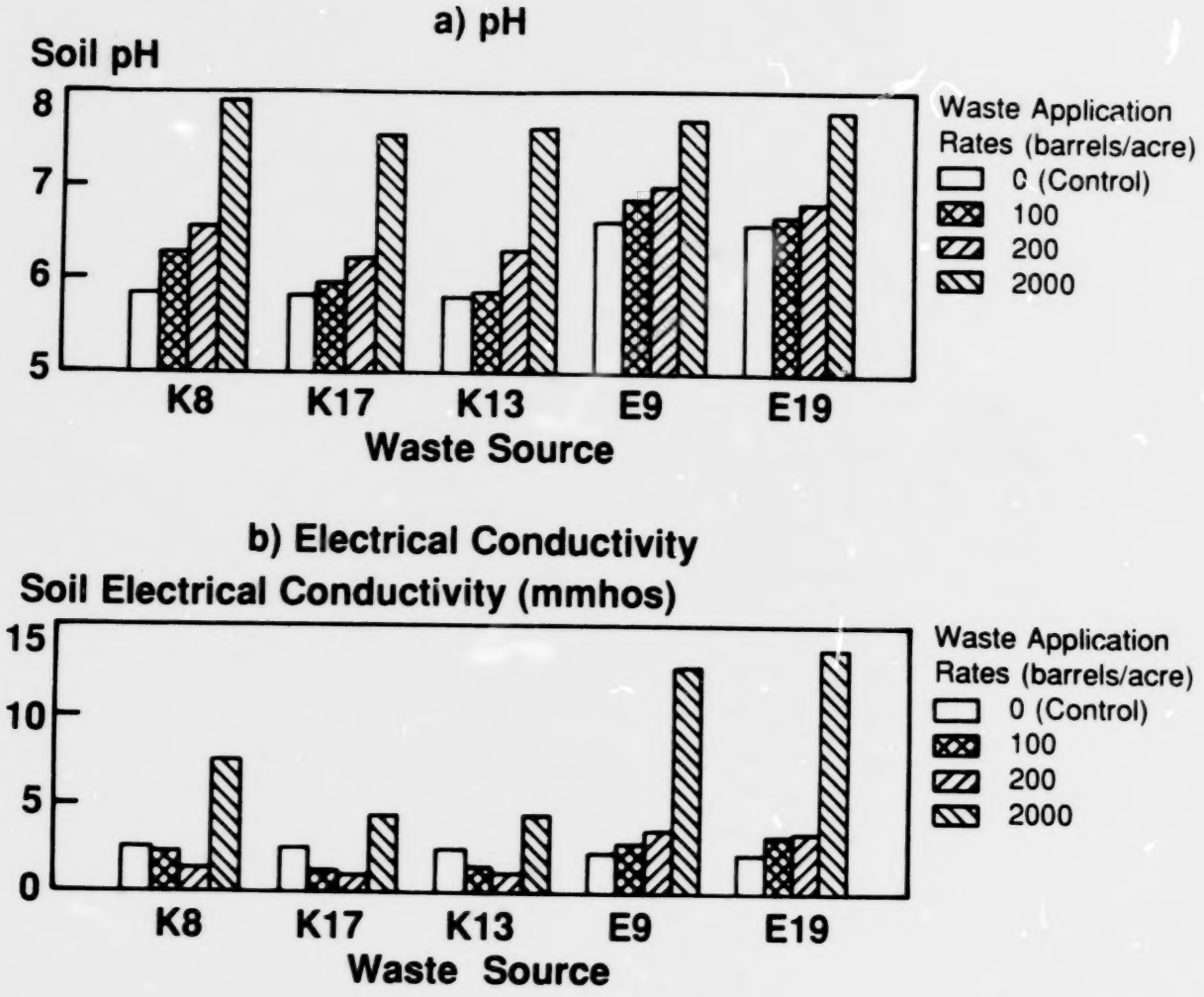


Figure 3.3 Effect of Waste Application on Soil pH and Electrical Conductivity Under Growth Room Conditions.

moderately saline conditions. In contrast, the Estevan waste samples (E9, E19), which contained high levels of soluble salts (>15,000 mg/L), raised soil salinity from slightly saline to severely saline conditions.

Water Soluble Ions

The main change in the water-soluble ions in the soil was the increase in sodium ion concentrations ($Na^+$). The very high application rate of the Kindersley wastes resulted in a 3- to 8-fold increase in $Na^+$ concentration, while the Estevan samples showed 13- to 14-fold increase in $Na^+$ with the same application rate. The lower application rates showed no significant increase in Na concentration.

Similarly, the other water soluble ions (with the exception of $Mg^{++}$) in the soil increased in concentration with the very high application rate. The magnitude of the increase was, however, much lower. $Mg^{++}$ concentration decreased with the moderate application rate.

Extractable Cations

The most prominent change in extractable cations in the soil as a result of waste application was the significant increase in extractable Na with the very high application rate (Figure 3.4). The increase ranged from 68% to 800%. The low and moderate rates did not result in any significant change in extractable Na.

Extractable Mg decreased significantly (11 to 36%) as a result of the very high application rates of the five waste samples used (Figure 3.4). The other rates reduced Mg slightly.

Extractable Ca increased (9 to 182%) as a result of the moderate and very high treatments. Little change was noted for extractable K.

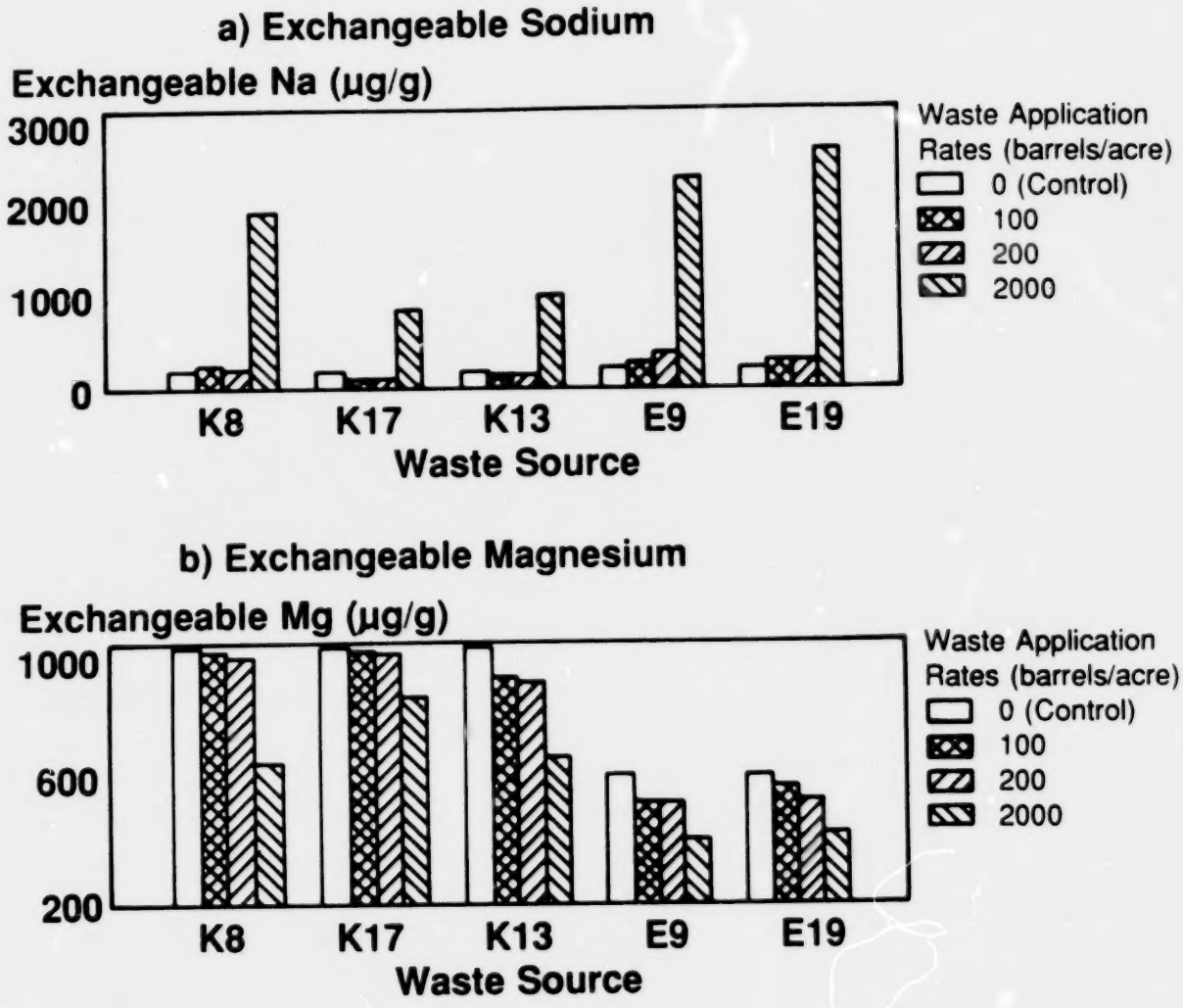


Figure 3.4 Effects of Waste Application on Extractable Sodium and Magnesium Under Growth Room Conditions.

Sodium Adsorption Ratio (SAR)

The high sodium adsorption ratios observed with the very high waste application rates are a reflection of the large increase in $Na^+$ concentrations indicated above. The K8 waste changed the soil from nonsodic to sodic conditions. The other Kindersley samples resulted in slightly sodic conditions. The Estevan waste samples resulted in highly sodic soil conditions (SAR of 28-30). Such conditions are expected to severely interfere with plant growth, mainly through altering the physical properties of the soil. Here, infiltration and hydraulic conductivity are reduced substantially.

Soil pH

Soil pH can affect plants directly or indirectly through effects on nutrient availability. The direct effects are usually associated with extreme pH levels, i.e. pH <4 or pH >8.5. Increase in soil pH could reduce the availability of most micronutrients.

The increase in soil pH was proportional to the waste application rate (Figure 3.3). The low application level resulted in a slight increase in pH in two cases (K8 and K17) while no significant change was noted for the others. The moderate application rate raised soil pH by 0.4 to 0.7 pH units, with the exception of E19 where pH remained nearly unchanged. The very high waste treatment raised soil pH by 1.1 to 2.1 pH units. Since the resultant soil pH levels were all below 8, no direct effects of soil pH is anticipated. However, the concentration of available micronutrients (e.g. manganese, zinc and copper) decreases with increase in soil pH.

Available Nutrients

While the addition of Estevan drilling wastes did not have much effects on available soil nutrients, some Kindersley wastes resulted in an increase in available nitrogen and/or phosphorous, particularly with the moderate and very heavy application rates (Figure 3.5). The largest increases (190 to 203%) in available phosphorous took place in the case of K17 and K13 waste samples which contained highest level of phosphorous. It should be noted also that the generally greater growth in the control plants (compared to those growing in the waste-treated pots) may have caused greater depletion of available P in the soil.

The level of available K was largely unaffected by the waste application.

Trace Elements

The loading rates for the trace elements of concern were calculated for the five drilling waste samples used at the three application rates employed (Table 3.3). These loadings may be compared to the maximum permissible cumulative metal loadings to agricultural land. The loading rates for all trace elements indicated here were much lower than the maximum permissible loading developed largely for use in conjunction with the land application of sewage sludge.

The application of drilling waste resulted in elevated levels of some trace elements in the treated soils as compared to the control soils (Table 3.4). Most of the increases (68%) were associated with the very high application rate (2000 barrels/acre). The most frequent changes in trace element concentration in the soil were the increase in total barium (Ba) and total copper (Cu). Other metals which showed in-

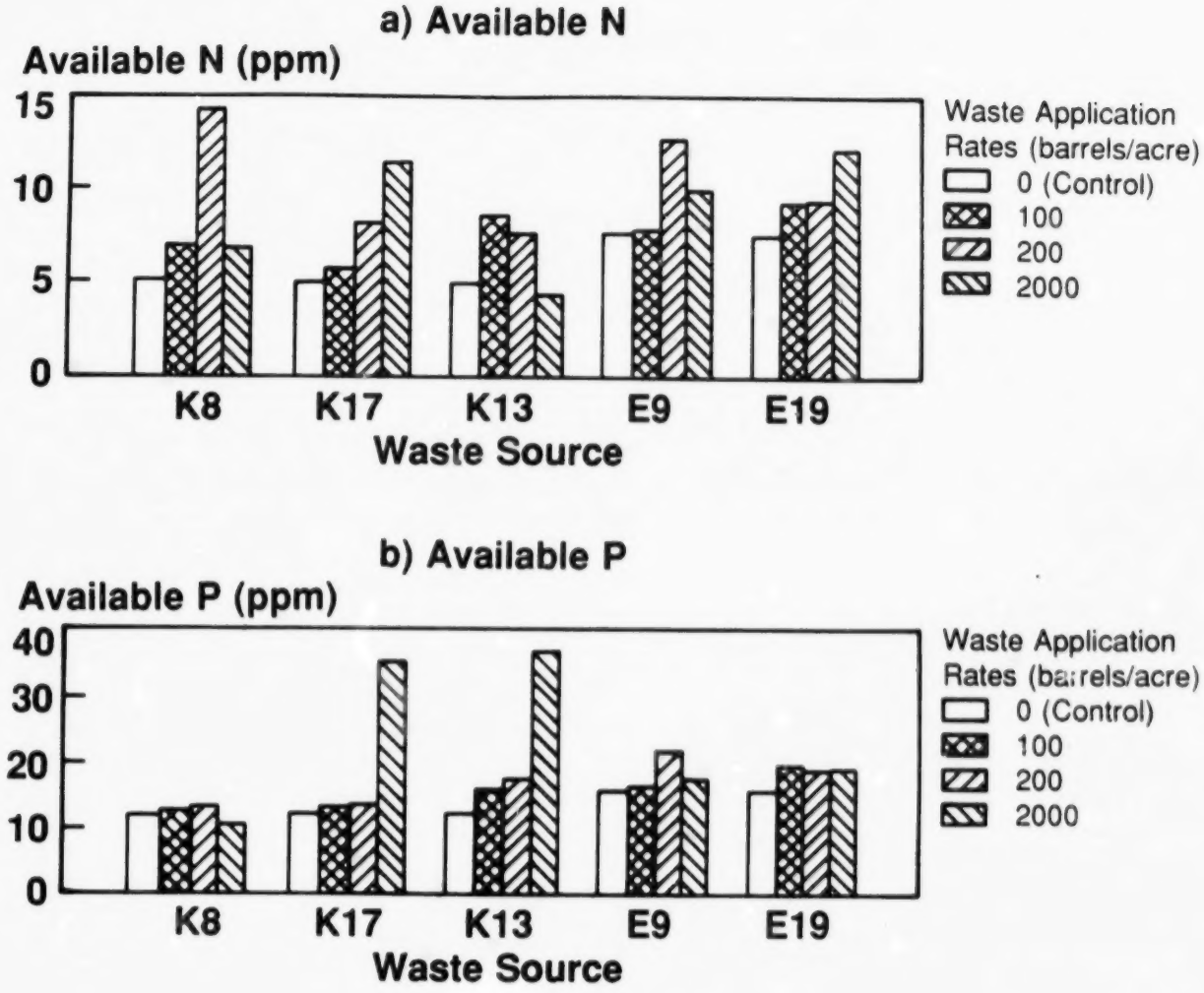


Figure 3.5 Effects of Waste Application on Available Soil Nitrogen and Phosphorous Under Growth Room Conditions.

Table 3.3 Range of Trace Element Loading Rates (kg/ha) Calculated for the Various Waste Application Rates.

| Application Rate (Barrels/ha) | B | Ba | Co | Cr | Cu | Mo | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 247 | 0.05-0.22 | 0.25-54 | 0.07-0.22 | 0.42-0.99 | 0.22-0.89 | 0.27-0.59 | 0.22-0.57 | 0.54-0.94 | 0.72-3.85 |
| 494 | 0.1-0.44 | 0.5-108 | 0.14-0.44 | 0.84-1.98 | 0.44-1.78 | 0.54-1.19 | 0.44-1.14 | 1.08-1.88 | 1.44-7.71 |
| 2000 | 0.99-4.45 | 4.94-1077 | 1.48-4.45 | 8.39-19.76 | 4.45-17.78 | 5.43-11.86 | 4.45-11.36 | 10.87-18.77 | 14.33-77.06 |
| Maximum Permissible Loading (kg/ha)* | 4.5-10 | -- | 0.25-30 | 4-1000 | 15-500 | 4 | 2-2000 | 1.5-2000 | 50-1000 |

*From data compiled by Abouguendia et al. (1985).

Table 3.4 Number of Experiments* in Which Significant Elevation (as compared to the control) in Soil Trace Element Concentration Occurred.

| Treatment** | B | Ba | Co | Cr | Cu | Mo | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 3 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 1 | 2 | 0 | 4 | 2 | 3 | 2 | 2 |

*Out of a total of five experiments.
**Treatments
2 100 barrels/acre
3 200 barrels/acre
4 2000 barrels/acre

crease in concentration included cobalt (Co), nickel (Ni), lead (Pb), molybdenum (Mo) and zinc (Zn). The increase in Mo concentration was restricted to the Estevan experiments, despite the fact that Mo levels in the Estevan wastes were similar to or lower than those of the Kindersley wastes. Most of the increases in Cu resulted from the Kindersley wastes which had, generally, higher Cu concentrations than the Estevan samples. Ba concentration was reduced with the high application of one of the Estevan samples. The same waste sample resulted a decrease in Pb concentration in the soil.

Available B in the Kindersley control soil used in the growth room experiments was deficient (<0.7 lb/acre, Saskatchewan Soil Fertility Committee). The addition of the waste at the low and moderate application rate, however, caused a significant increase in available B with all waste samples used. The levels of B associated with the very high application rate are adequate for plant growth. None of the B concentrations found in this study is considered phytotoxic.

All levels of trace elements in the soil found in this study are within the levels considered normal for noncontaminated soils, with the exception of Mo. Mo concentrations in both the treated and the control soils were higher than ranges reported for normal soils (Bear 1964).

### 3.1.3.2 Plants

Yield

The effect of drilling waste application on wheat grain yield varied with the waste sample and the application rate (Figure 3.6, Tables 3.5 and 3.6). The Kindersley sample K13 had no effect on grain production at any of the rates used. The same sample had no detrimental ef-

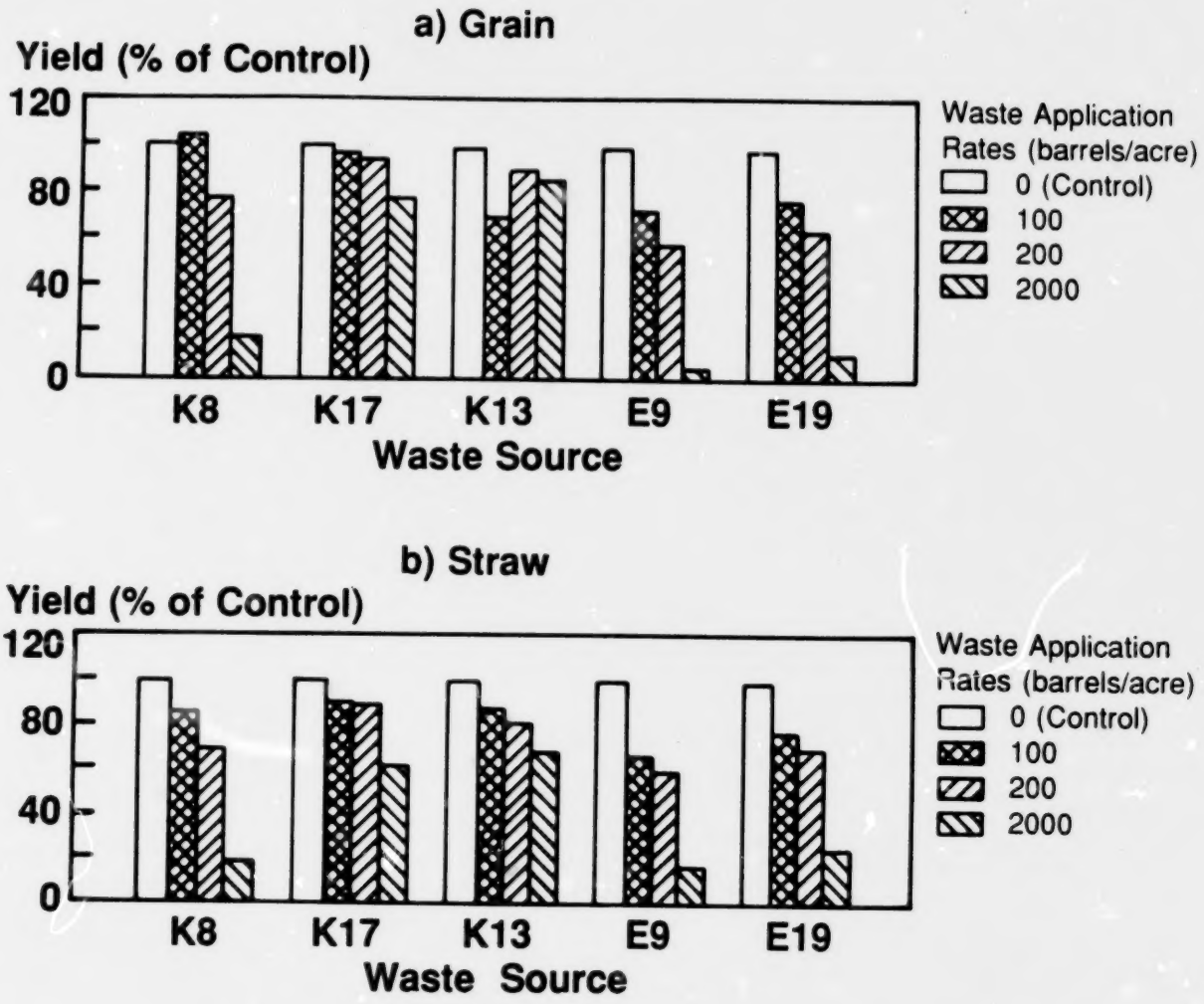


Figure 3.6 Effects of Waste Application on Grain and Straw Yield of Wheat Under Growth Room Conditions.

Table 3.5 Summary of the Yield Statistical Significance Tests for the Growth Room Experiments.

| Waste Source | Grain | | | Straw | | |
|---|---|---|---|---|---|---|
| | 2* | 3 | 4 | 2 | 3 | 4 |
| K8 | 0** | - | -- | -- | -- | -- |
| K13 | 0 | 0 | 0 | 0 | -- | -- |
| K17 | 0 | 0 | - | 0 | 0 | -- |
| E9 | 0 | -- | -- | -- | -- | -- |
| E19 | 0 | -- | -- | - | -- | -- |

*Treatments

2 100 barrels/acre
3 200 barrels/acre
4 2000 barrels/acre

**

- Significantly lower than the control at the 0.05 level.
-- Significantly lower than the control at the 0.01 level.
0 No significant difference from the control.

Table 3.6 Summary of the Yield Data (mg/plant) from the Growth Room Experiments. (Means followed by standard deviation.)

| Waste Source Treatments | Grain | Straw |
|---|---|---|
| K8 | | |
| 1 | 715 (105) | 1127 (60) |
| 2 | 674 (56) | 966 (59) |
| 3 | 550 (157) | 772 (105) |
| 4 | 135 (63) | 198 (98) |
| CR (0.05) | 141 | 114 |
| (0.01) | 176 | 142 |
| K13 | | |
| 1 | 715 (105) | 1127 (60) |
| 2 | 506 (266) | 996 (150) |
| 3 | 650 (101) | 913 (165) |
| 4 | 624 (85) | 771 (85) |
| CR (0.05) | 215 | 168 |
| (0.01) | 269 | 210 |
| K17 | | |
| 1 | 715 (105) | 1127 (60) |
| 2 | 700 (108) | 1010 (112) |
| 3 | 680 (84) | 1008 (181) |
| 4 | 558 (109) | 684 (141) |
| CR (0.05) | 139 | 179 |
| (0.01) | 174 | 224 |
| E9 | | |
| 1 | 631 (86) | 837 (76) |
| 2 | 468 (119) | 556 (103) |
| 3 | 374 (192) | 498 (231) |
| 4 | 46 (54) | 134 (97) |
| CR (0.05) | 169 | 192 |
| (0.01) | 212 | 240 |
| E19 | | |
| 1 | 631 (86) | 837 (76) |
| 2 | 496 (176) | 644 (226) |
| 3 | 413 (98) | 577 (110) |
| 4 | 84 (53) | 203 (50) |
| CR (0.05) | 154 | 182 |
| (0.01) | 193 | 228 |

Treatments
1 0 barrels/acre (control)
2 100 barrels/acre
3 200 barrels/acre
4 2000 barrels/acre
CR Critical Range (based on Tukey's HSD Test).

fect on the final seedling emergence as indicated above. The other Kindersley samples reduced grain yield mainly with the very high application rate (2000 barrels/acre).

The Estevan samples (E9 and E19) resulted in significant reduction in grain yield with both the moderate and the very high application rates. The reduction ranged from 35 to 41% with the moderate application rate (200 barrels/acre) and from 87 to 93% with the very high application rate.

All five waste samples reduced straw yield significantly (32 to 84% with the very high application rate. With the exception of K17, the waste samples tested caused reduction in straw production when applied at a moderate rate. Samples K8 and E9 caused significant reduction (14 and 34%) in straw yield with the low application rate (100 barrels/ - acre). Therefore, it appears that straw production is more sensitive to drilling waste application than grain yield, i.e. reduction in above ground biomass is not necessarily accompanied by a reduction in grain yield.

Grain and straw yield as a function of waste application rate is illustrated in Figures 3.7, and 3.8, respectively. From these figures, it may be possible to obtain an indication of the reduction in grain and straw yield with the addition of various rates of drilling wastes of similar characteristics. Greater yield reduction is noted for the Estevan than for the Kindersley wastes.

A strong correlation was found between yield and waste salinity data. At the 100 barrels/acre, grain yield showed a relatively strong negative correlation with total dissolved solids (TDS) ($r = -0.73$). Other salinity parameters, e.g. water soluble $Na^{+}$ and $SO_4^{--}$, also, show-

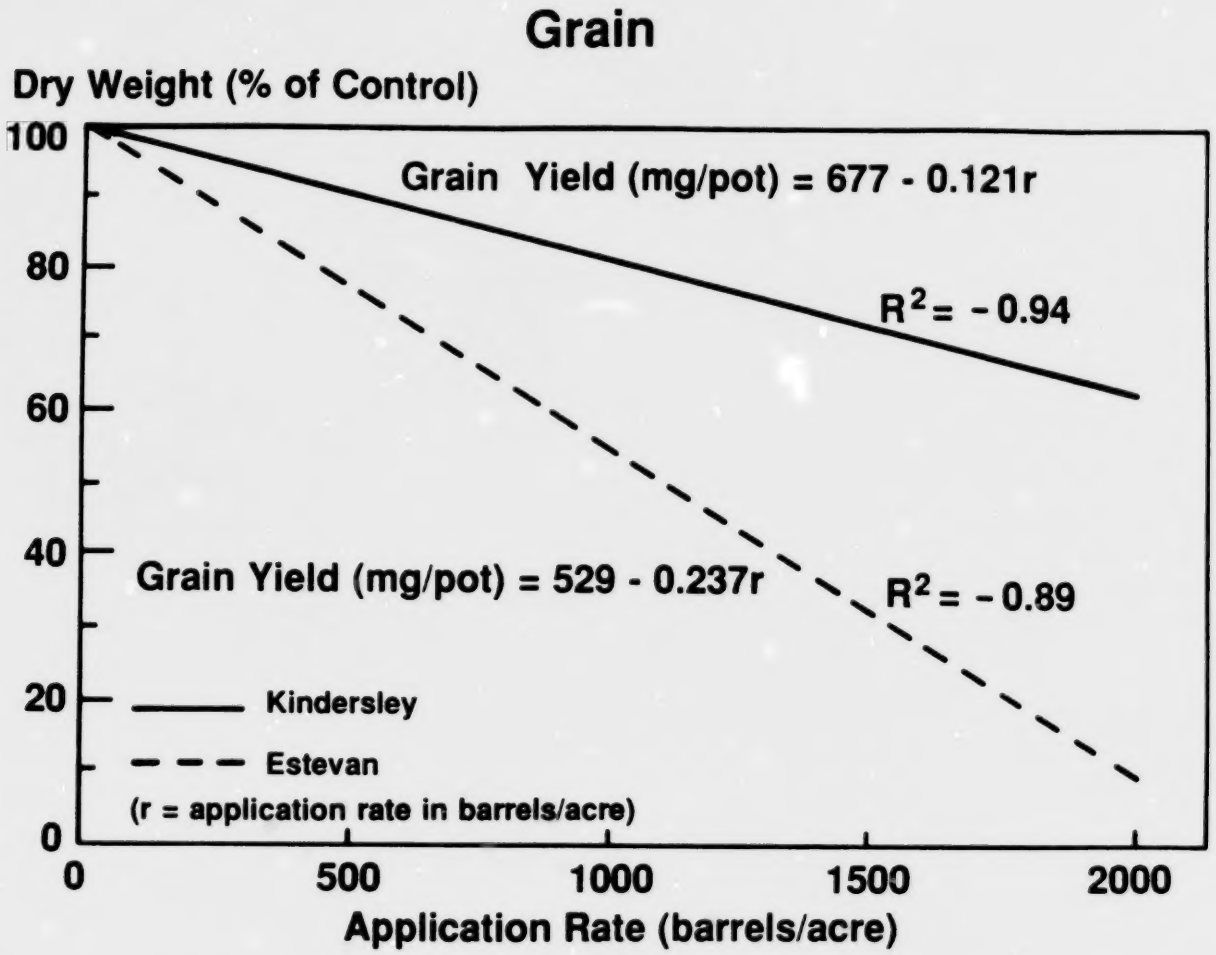


Figure 3.7 Relationship Between Grain Yield and Waste Application Rate Under Growth Room Conditions.

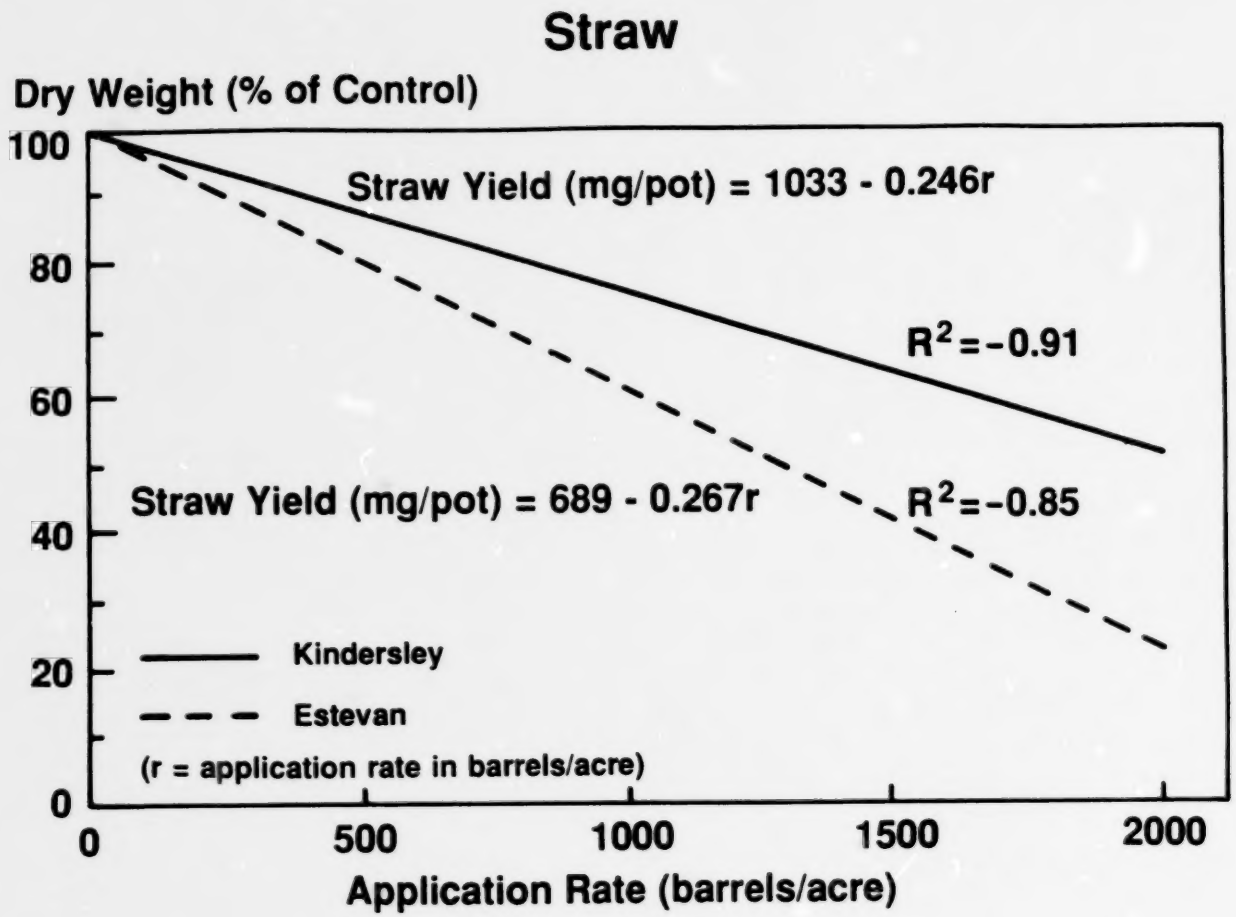


Figure 3.8 Relationship Between Straw Yield and Waste Application Rate Under Growth Room Conditions.

ed a relatively strong negative correlation with grain yield. Straw yield, at the same application rate, showed the strongest correlation with TDS ($r = -0.97$), and water soluble $SO_4$ ($r = -0.98$), Na ($r = -0.96$), and Cl ($r = -0.94$). Similar correlations were found with the higher application rates.

Grain yield was also correlated with soil electrical conductivity (Figure 3.9). The correlation was particularly strong in the case of the Estevan experiments ($r = -0.89$ for Estevan and $r = -0.59$ for Kindersley), indicating a possible dominant role of salinity.

It is interesting to note that grain and straw production was positively correlated with total phosphorous in the waste. This correlation was particularly strong in the case of the moderate and very high application rates. As indicated above (Section 3.1.3.1), the level of available phosphorous in the control soils was low and available phosphorous increased with waste application in a number of cases.

Trace Element Uptake

The increase in trace element concentration in wheat grain was generally restricted to the very high application rates (Table 3.7). Elements which showed elevated concentrations in grain were boron (four cases), Cu and Zn (two cases each) and chromium (Cr) and Ni (one case each). The increase in B, Zn and Cu concentration in the grain was a reflection of the increase in their levels in the soil. However not all changes in trace element concentrations in the grain were correlated with the changes in soil concentrations. For example, no increase in Ba, Co, Mo and Pb concentrations in the grain were noted despite their elevated levels in the soil. This could be due to low availability for

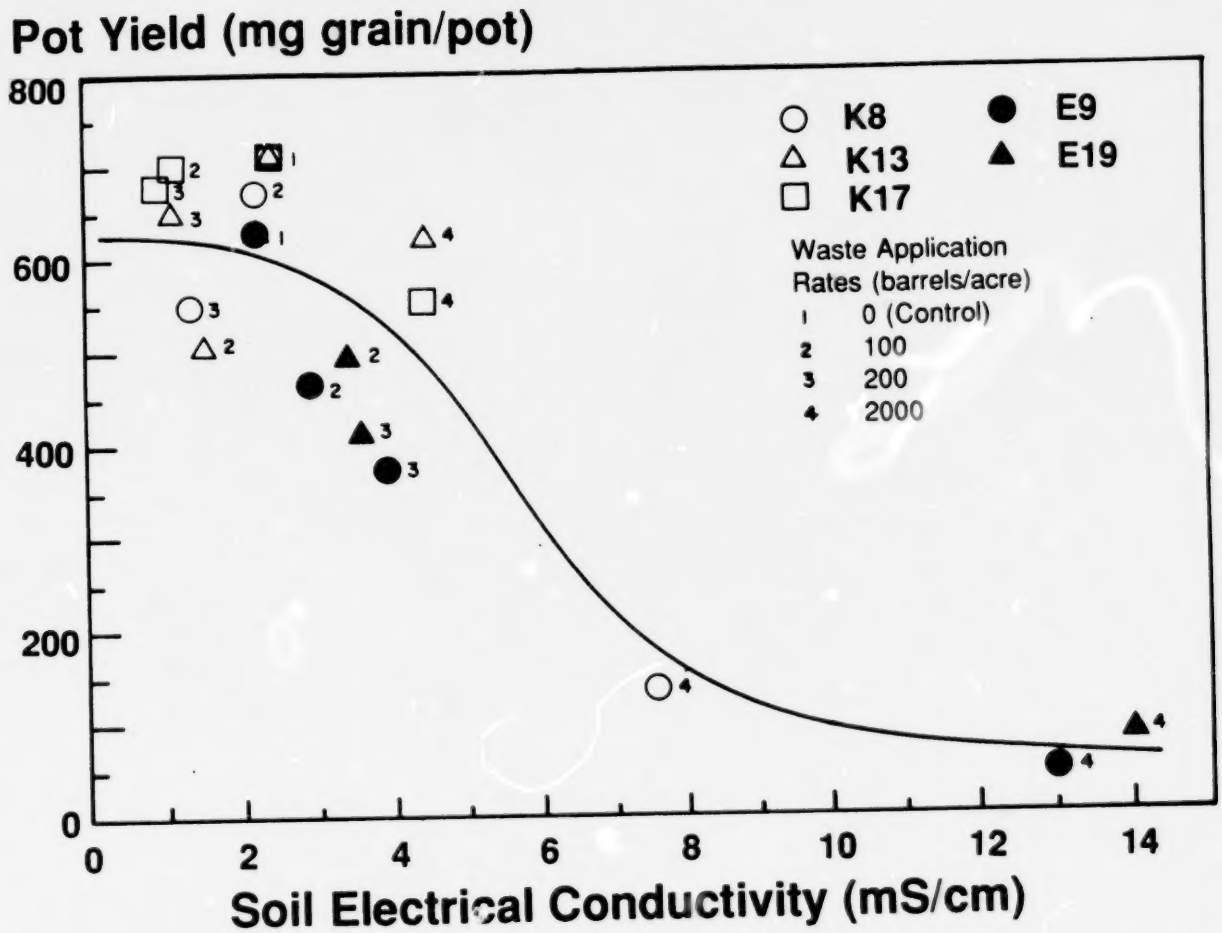


Figure 3.9 Relationship Between Grain Yield and Electrical Conductivity of the Soil at the End of The Growth Room Experiments.

Table 3.7 Number of Experiments* in Which Trace Element Levels in the Grain Was Elevated (as compared to the control) as a Result of Drilling Waste Application.

| Treatment** | B | Ba | Co | Cr | Cu | Mo | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 4 | 0 | 0 | 1 | 2 | 0 | 1 | 0 | 2 |

*Out of five experiments carried out.
**Treatments
2 100 barrels/acre
3 200 barrels/acre
4 2000 barrels/acre

plant uptake and/or lack of translocation to the grain.

With the exception of Mo, all increases in trace element concentrations in the straw were associated with the very high application rate (Table 3.8). Trace elements which showed elevated levels in the straw were Mo (five cases), B (three cases), Co (two cases), Pb (one case) and Zn (one case).

In general, the increase in B, Co, Mo, Pb and Zn levels in straw was associated with elevated levels of these elements in the soil. It is noted, however, that in a number of cases Mo concentration in straw increased significantly despite the lack of significant increase in total Mo in the soil. Mo availability increases with increase in soil pH up to a pH of 6.5-7.0. No increase in Ba, Cu and Ni concentration was noted despite their elevated levels in the soil. The availability of many trace elements is reduced at pH levels such as those reported in this study.

The uptake of trace elements by plants is influenced by many factors including soil pH, soil cation exchange capacity, soil organic matter content, the concentration and chemical form of the metal, and plant species. pH appears to be a major factor affecting the availability of trace elements. The availability of most trace elements in reduced with the rise in soil pH.

The trace element transfer coefficients from soil to the plant (as indicated by the ratio of total plant concentration to total soil concentration) were generally lower than 1 and mostly below 0.5, indicating that wheat does not accumulate trace elements in its tissues. The few exceptions noted were associated with the very high application rate. The relatively high soil pH and the possible increase in soil pH result-

Table 3.8 Number of Experiments* in Which Trace Element Levels in the Wheat Straw Was Elevated (as compared to the control).

| Treatment** | B | Ba | Co | Cr | Cu | Mo | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| 4 | 3 | 0 | 2 | 0 | 0 | 5 | 0 | 1 | 1 |

*Out of five experiments carried out.
**Treatments
2 100 barrels/acre
3 200 barrels/acre
4 2000 barrels/acre

ing from waste application are possible reasons for the low plant uptake of trace elements.

Levels of trace elements in wheat grain and straw are within those considered normal for plant tissues according to Chaney (1982). The only exception is Mo concentration in the straw. Mo levels in many cases were higher than the normal of 0.1-0.3 mg/kg. Only in two cases (both associated with the very high application rate), were Mo levels near or higher than the maximum tolerated by cattle (10 mg/kg). It is also noted that the Cu:Mo ratio in the straw was less than 2:1 in most cases (even in the Estevan control treatment). Ratios of Cu to Mo of less than 2:1 are known to cause molybdenosis symptoms in cattle (Dollahite et al. 1972). Molybdenosis is a nutritional imbalance which results from deficient Cu and/or from excess Mo in forage material.

## 3.2 Field Investigations

General information on the sites investigated is given in Table 2.4, while available drilling fluids formulations are given in Tables 2.6 and 2.7. A list of the soil and plant parameters investigated at each of the sites selected is given in Table 2.10.

### 3.2.1 Drilling Waste Characteristics

Characteristics of the five drilling waste samples used in the growth room experiments have already been given in Section 2.1. Four of those waste sources were also involved in the field investigations. Information on additional waste material used in the field is given in Tables 2.8 and 2.9.

### 3.2.2 Soils

Electrical Conductivity

No significant change in soil electrical conductivity was found in the 0-15 and 15-30 cm soil layers at any of the sites investigated with the exception of one Estevan site (E22) (Table 3.9). At the latter site, electrical conductivity of the 15-30 cm layer increased from 0.5 to 2.8 mS/cm. This means a change in soil salinity from nonsaline to slightly saline. Therefore, little, if any, effect on crop yield is expected.

Soil salinity was also surveyed using an electromagnetic terrain conductivity meter (EM38). This survey provides a wider coverage than core sampling and enables an assessment of the salinity pattern in the on-lease disposal sites. The EM38 data showed no significant differences in electrical conductivity between the treated off-lease disposal sites and their respective control sites (Table 3.10). This is in agreement with the detailed salinity analysis of soil samples collected. In contrast, six of the on-lease disposal sites exhibited greater salinity than the control. Only one of these sites was detected using the soil coring and analysis technique. The EM38 technique, as noted above, enables more comprehensive coverage of the site area than is possible with the soil coring and analysis technique.

Water Soluble Ions

The Kindersley salinity data showed an increase in water soluble sodium in the 0-15 cm soil layer at two (K17, K21) of the seven sites investigated (Table 3.9). At one of those sites (K21), $SO_4^{--}$ concentration was, also, greater in the disposal area than in the nontreated con-

Table 3.9 Changes in Soil Salinity in Treated Sites as Compared to the Control Soils*.

| Region Site No. | | pH | Electrical Conductivity | Water Soluble Ions | | | | | | SAR |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Na | Ca | Mg | K | Cl | $SO_4$ | |
| Kindersley | | | | | | | | | | |
| K3 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lower | 0 | 0 | 0 | 0 | 0 | 0 | + | 0 | 0 |
| K8 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| K16 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| K17 | Upper | ++ | 0 | ++ | 0 | 0 | 0 | 0 | 0 | ++ |
| K21 | Upper | 0 | 0 | ++ | 0 | 0 | 0 | 0 | + | ++ |
| K24 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| K30 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Estevan | | | | | | | | | | |
| E1 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lower | 0 | 0 | 0 | 0 | 0 | 0 | + | 0 | 0 |
| E2 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lower | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E20 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lower | 0 | 0 | 0 | 0 | 0 | 0 | + | 0 | 0 |
| E22 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Lower | 0 | ++ | 0 | ++ | ++ | ++ | 0 | ++ | 0 |
| E9 | Upper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*++ Significantly higher than the control at the 0.01 level.
+ Significantly higher than the control at the 0.05 level.
0 Not significantly different from the control.
Upper 0-15 cm
Lower 15-30 cm

Table 3.10 Summary of the Statistical Significance Test Results* of the EM38 Soil Electrical Conductivity Data.

| Region Site No. | Soil Depth 0-15 cm | Soil Depth 15-30 cm |
|---|---|---|
| Kindersley | | |
| K1 | + | + |
| K3 | 0 | 0 |
| K8 | 0 | 0 |
| K16 | 0 | 0 |
| K17 | 0 | 0 |
| K21 | 0 | 0 |
| K24 | 0 | 0 |
| K30 | 0 | 0 |
| Estevan | | |
| E1 | 0 | 0 |
| E2 | + | + |
| E9 | + | + |
| E15 | 0 | 0 |
| E16 | 0 | 0 |
| E20 | 0 | 0 |
| E21 | + | + |
| E22 | ++ | ++ |
| E28 | ++ | ++ |
| E29 | 0 | 0 |

* + Significantly greater than the control at the 0.05 level.
++ Significantly greater than the control at the 0.01 level.
0 Not significantly different from the control.

trol. The water soluble sodium in the K17 sample was rather low (530 mg/L). No chemistry data are available for K21. The main source of sodium in the fresh-water based drilling fluids used in the Kindersley area is caustic soda (Table 2.6, see also Abouguendia et al. 1985).

Chloride concentration increased in the 15-30 cm at the K3 site. The K3 waste analysis indicated no salinity problem. However, it should be remembered that the material available for analysis was in the form of dry mud scraped from the soil surface. The chloride ion, therefore, must have been removed from the waste, especially with the above-normal precipitation in 1986. The Estevan salinity data indicated significant increase in $Cl^-$ concentration in the 15-30 cm soil layer at two sites (E1 and E20). Site E22 showed an increase in the concentration of the water soluble $Ca^{++}$, $Mg^{++}$, $K^+$, and $SO_4^{--}$. Chloride level in the E20 and E22 samples was 2600 and 1630 ppm, respectively. No data is available for E1. The main sources of salinity in the drilling fluids used at E20 and E22 were calcium chloride (total of 1140 to 1360 kg per), and caustic soda (total of 180 to 360 kg).

Extractable Cations

Little change in extractable cations was found as a result of waste application. One site (K3) exhibited an increase in exchangeable K and another site (K17) showed an increase in exchangeable Ca, Na and K. In the remaining six sites, no statistically significant differences from the control were noted.

Sodium Adsorption Ratio

The two Kindersley sites which had increases in water soluble $Na^+$

showed also an increase in sodium adsorption ratio (Table 3.9). The increases, however, were small and the soils are still considered non-sodic and no adverse effects on crop growth or yield are expected.

pH

One of the two sites which had increased water soluble $Na^+$ exhibited also an increase in soil pH (from 4.94 to 5.44) (Table 3.9). This change in soil pH is not expected to have any adverse effects on crop growth or yield. Production of such forage crops as alfalfa may even benefit from such change in soil pH.

Available Nutrients

The effect of waste application on the available soil macronutrients was minimal. The level of available K at site K3 was greater in the treated area than in the control area. Available phosphorous in the 0-15 cm soil layer at site K16 was reduced. This reduction in available P was not expected in view of the phosphorus added in the waste. However, the added P may not have been in an available form and changes in soil properties may have resulted in a reduction in phosphorous availability.

Trace Elements

Of the four Kindersley sites investigated, only one site (K8) showed elevated levels of trace elements (Table 3.11). In this site, a significant increase in the total concentration of Ba, Co, Cu, Mo, Ni and Zn was found. The increases were largely restricted to the 0-15 cm soil layer, indicating little or no downward movement of these elements.

Table 3.11 Changes in Soil Trace Element Concentrations in Treated as Compared to the Control Soils.

| Region Site No. | B | | Ba | | Co | | Cr | | Cu | | Mo | | Ni | | Pb | | Zn | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A* | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| Kindersley | | | | | | | | | | | | | | | | | | |
| K3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 |
| K8 | 0 | 0 | ++ | + | + | 0 | + | 0 | + | 0 | + | 0 | + | 0 | 0 | 0 | + | 0 |
| K16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| K17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Estevan | | | | | | | | | | | | | | | | | | |
| E1 | 0 | - | + | 0 | 0 | 0 | 0 | 0 | + | 0 | + | + | 0 | - | 0 | 0 | + | 0 |
| E2 | 0 | 0 | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E20 | 0 | 0 | 0 | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ++ | 0 | 0 | 0 | 0 | 0 |
| E22 | 0 | 0 | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | + | 0 | 0 |

\+ Significantly greater than the control at the 0.05 level.
++ Significantly greater than the control at the 0.01 level.
\- Significantly lower than the control at the 0.05 level.
-- Significantly lower than the control at the 0.01 level.
0 Not significantly different from the control.

*A 0-15 cm layer
B 15-30 cm layer

Some Estevan sites exhibited increase in total Ba concentration (Table 3.11). The increases were largely restricted to the 0-15 cm soil layer. Sites E1 and E2 exhibited an increase in Mo concentration. Increases in Cu, Ni, Pb, and Zn concentrations were noted at one site each. In very few cases, the total concentration of some trace elements (B, Ni and Pb) was lower in the treated areas than in the control areas.

The level of available soil boron (B) was largely unaffected by the waste application. Of the nine sites for which data were available, only K17 showed reduction in available B. A slight reduction in the level of available B was noted with the 100 barrels/acre treatment in the growth room experiment which utilized the K17 waste sample. No change in available B was found in the remaining sites.

All levels of trace elements in the soil reported here are still within the range reported for normal soils (see, for example, data compiled by Abouguendia et al. 1985) with the exception of Mo. Mo concentration in both the control and treated Kindersley soils was, generally, slightly higher than the Mo concentration range considered as normal for non-contaminated soils (Bear 1964).

### 3.2.3 Crops

Plant Density and Height

Of the sixteen sites investigated, only two sites had a significantly lower plant density in the treated area than in the control (Table 3.12). Two other sites showed increased density in the treated area compared to the control. In the remaining sites, plant density was similar in the treated and the nontreated areas. Plant density is a function of many factors including time of seeding, seeding rate, soil

Table 3.12 Summary of the Plant Density and Height Statistical Significance Tests*.

| Region Site No. | Crop | Plant Density | Plant Height |
|---|---|---|---|
| Kindersley | | | |
| K1 | Barley | 0 | 0 |
| K3 | Durum wheat | + | - |
| K8 | Barley | -- | 0 |
| K16 | Mustard | 0 | 0 |
| K21 | Hard red spring wheat | + | 0 |
| K24 | Barley | 0 | 0 |
| K30 | Barley | 0 | 0 |
| Estevan | | | |
| E1 | Hard red spring wheat | 0 | 0 |
| E2 | Hard red spring wheat | 0 | -- |
| E15 | Hard red spring wheat | 0 | 0 |
| E16 | Hard red spring wheat | 0 | 0 |
| E20 | Hard red spring wheat | 0 | -- |
| E21 | Winter wheat | 0 | 0 |
| E22 | Hard red spring wheat | 0 | 0 |
| E28 | Hard red spring wheat | - | 0 |
| E29 | Barley | 0 | 0 |

* + Significantly greater than the control at the 0.05 level.
- Significantly lower than the control at the 0.05 level.
-- Significantly lower than the control at the 0.01 level.

moisture and soil salinity. The reduction in plant density at the Kindersley site (K8) agrees with the seedling emergence experiment. The possible causes of this reduction have already been discussed in Section 3.1.2. The reduction in plant density at the Estevan site (E28) appeared to be related to the increase in soil salinity in the treated area (Table 3.10). The increase in plant density noted for some treated areas could be due to possible improvement in soil water holding capacity in the treated area as a result of the added bentonite. Another possible explanation is that some farmers tend to employ a heavier seeding rate in areas receiving wastes.

Plant height was lower in the treated area than in the control area at one Kindersley site (K3) and at two Estevan sites (E2) and E20). No apparent differences in plant height were found between the treated and the non-treated areas at the remaining 13 sites.

The reduction in plant height at the K3 site could not be explained on the basis of the available soil chemistry data. Water soluble chloride was greater in the treated area than in the control but that increase was not considered sufficiently high to cause significant growth reduction. A possible explanation is the higher plant density found in the treated area at this site. Competition for such factors as soil moisture and plant nutrients may have reduced plant growth. The reduced plant height noted at site E2 was likely caused by the increased soil salinity (Table 3.10), while increased water soluble chloride may have caused the reduced plant height at site E20 (Table 3.9).

Yield

Grain yield was reduced at only one site (K21) out of the six sites

studied in the Kindersley region (Table 3.13). The K21 site showed significant increase in water soluble Na and $SO_4^{--}$. No reduction in straw yield was noted at any of the Kindersley sites.

Although wheat grain yield was not affected at any of the sites investigated in the Estevan region, straw yield was reduced at two sites (E2 and E20). These are the same sits where plant height was also reduced. As explained above, salinity was the likely cause for the reduced straw yield.

Trace Element Uptake

The trace element transfer coefficients from the soil to the plant were found to be, generally, lower than 1 and mostly below 0.5, indicating that the crop plants investigated do not accumulate trace metals in their above ground tissues. The relatively high soil pH and the possible increase in soil pH resulting from waste application are the likely reasons for the low plant uptake of trace elements despite the elevated levels of some trace elements in the soil at a few sites.

The trace element concentrations in the grain produced in the treated areas were generally similar to those of the control areas. Elevated trace element concentrations in the grain were restricted to a few cases: Ba (two out of eight cases), and Zn (one case). In a few cases, the concentration was actually lower in the treated area than in the control.

No significant increase in trace element concentrations was found in the straw produced in the treated areas in comparison to those from the control areas. A drop in trace element concentration occurred in two cases (B in site K16 and Ba in site K21). No significant difference

Table 3.13 Summary of the Yield Statistical Significance Tests (Field Study).*

| Region Site No. | Crop | Grain or Seeds | Straw |
|---|---|---|---|
| Kindersley | | | |
| K3 | Durum wheat | 0 | 0 |
| K8 | Barley | 0 | 0 |
| K16 | Mustard | 0 | 0 |
| K21 | Hard red spring wheat | - | 0 |
| K24 | Barley | 0 | 0 |
| K30 | Barley | 0 | 0 |
| Estevan | | | |
| E1 | Hard red spring wheat | 0 | 0 |
| E2 | Hard red spring wheat | 0 | - |
| E20 | Hard red spring wheat | 0 | - |
| E22 | Hard red spring wheat | 0 | 0 |

* - Significantly lower than control at the 0.05 level.
-- Significantly lower than control at the 0.01 level.
+ Significantly greater than control at the 0.05 level.
++ Significantly greater than control at the 0.01 level.
0 Not significantly different from the control.

in total boron concentration was found between treated and nontreated soils at the K16 site.

Levels of trace elements in wheat grain and straw are within those considered normal for plant tissues according to Chaney (1982).

### 3.2.4 Grasslands

Only one grassland site was available for evaluation. This Kindersley site (K22) is a mixed grass prairie type dominated by needle-and-thread grass (Stipa comata) and pasture sage (Artemisia frigida). The volume of waste spread on this site is not known. However, the disposal rate was estimated to be 1300 to 5300 barrels/acre as calculated from mud thickness information.

Spreading of the waste resulted in substantial reduction in total vegetation ground cover, total vegetation yield and the number of species present. Also, some changes in species composition was noted. The proportions contributed by the low growing sedges and moss phlox were reduced as a result of waste application. Vegetation recovery is expected to take place because of the low salinity and sodicity of the waste used at this site. The rate of recovery is, however, difficult to predict. It may be of interest to carry out further evaluation of this site.

The concentrations of most trace elements in grasses and pasture sage increased significantly as a result of waste application. Some of the increase in trace element concentration may be due to contamination of plant surfaces as they pushed through the mud layer. Mo and Pb levels in the two types of vegetation sampled exceed the maximum level chronically tolerated by cattle according to Chaney (1982).

# 4 CONCLUSIONS

## 4.1 Growth Room Experiments

### 4.1.1 Soil Characteristics

(1) The effect of drilling waste on soil characteristics was influenced strongly by the rate of application and the chemical characteristics of the waste.

(2) Application of up to 200 barrels/acre of waste had no significant effect on soil salinity. Waste applied at 2000 barrels/acre could cause significant change in soil salinity and sodicity.

(3) In general, the low waste application rate (100 barrels/acre) did not result in significant changes in soil extractable cations, sodium adsorption ratio or pH.

(4) The moderate waste application rate (200 barrels/acre) could result in minor adverse changes in soil extractable cations, sodium adsorption ratio and pH.

(5) The excessive application rates (2000 barrels/acre) could have substantial adverse effects on soil extractable cations, sodium adsorption ratio and pH.

(6) Waste application had no adverse effects on the level of available soil macronutrients (N, P, and K). Increase in the concentration of the available N and P may take place depending on waste chemistry.

(7) Waste application, particularly at high application rate increased available soil boron and appeared to have corrected boron deficiency in some cases.

(8) The loading rates (based on application rates ranging from 100 to 2000 barrels/acre) for the trace elements of concern were found to be within the maximum permissible cumulative loadings developed for use in

conjunction with the land application of sewage sludge.

(9) In general, waste application resulted in elevated levels of some trace elements (B, Ba, Cu, Co, Ni, Mo, and Pb) in the soil. These elevated levels were, generally, associated with the very high application rate (2000 barrels/acre).

(10) All levels of trace elements in the soil found in this study are within the levels considered normal for noncontaminated soils, with the exception of Mo. Mo concentrations in both the treated and the control soils were higher than the ranges reported for normal soils.

### 4.1.2 Seed Germination and Seedling Emergence

(11) Wheat seed germination did not appear to be sensitive to the drilling waste samples used in this study.

(12) The effect of soil-applied drilling wastes on seedling emergence of the common agricultural crops appeared to depend on the waste characteristics and the waste application rate.

(13) Waste application rates of up to 200 barrels per acre did not affect seedling emergence of Columbus and Katepwa wheat, barley or alfalfa. Higher rates of application could result in a reduction in seedling emergence. High salinity and sodicity of the waste appeared to be the main factors affecting seedling emergence.

### 4.1.3 Yield

(14) The effect of drilling waste application on wheat grain yield varied with the waste characteristics and the waste application rate. The main effect noted was a reduction in grain and/or straw yield in response mainly to the moderate (200 barrels/acre) and the very high

(2000 barrels/acre) application rates. One waste samples had no effect on wheat grain yield even when applied at a rate of 2000 barrels/acre. Grain yield appeared less sensitive to waste application than straw yield.

(15) Yield results are strongly related to the salinity level of the applied waste and the salinity of the treated soil, suggesting salinity as the main cause of wheat yield reduction.

### 4.1.4 Trace Element Uptake by Plants

(16) Waste applied at rates of up to 200 barrels/acre had no effect on the levels of trace element concentration in wheat grain. In some cases, the high application rates resulted in an increase in the concentration of some trace elements (B, Cr, Cu, Ni and Zn) in wheat grain.

(17) Application rates of up to 200 barrels/acre had no effect on the concentration of trace elements, with the exception of Mo, in wheat straw. Mo concentration increased with all rates of application used (100 to 2000 barrels/acre).

(18) In general, wheat did not appear to accumulate trace elements in its tissues. The few exceptions noted were associated with the very high application rate. The relatively high soil pH and the possible increase in soil pH resulting from waste application may be the reasons for the low plant uptake of trace elements.

(19) Levels of trace elements in wheat grain and straw are within those considered normal for plant tissues according to Chaney (1982). The only exception is Mo concentration in the straw. Mo levels in many cases were higher than the normal of 0.1-0.3 mg/kg. Only in two cases (both associated with the very high application rate), were Mo levels at

or higher than the maximum tolerated by cattle (10 mg/kg).

(20) The Cu:Mo ratio in the straw was less than 2:1 in most cases (even in one control treatment). Ratios of Cu to Mo of less than 2:1 in cattle diet could cause nutritional imbalances.

## 4.2 Field Investigations

### 4.2.1 Soil Characteristics

(21) Present off-lease disposal practices did not appear to cause change in soil salinity. In contrast, 50% of the on-lease disposal sites showed increase in soil salinity. However, the increase in salinity involves only small portion of the lease. The main water soluble ions causing salinity were Na, Cl and $SO_4$. The increase in soil salinity appears to be, in general, related to the salinity of the waste.

(22) Under field conditions, waste application had, generally, little effect on extractable cations, sodium adsorption ratio, and pH of the soil.

(23) Drilling waste application had little effects on the available soil macronutrients.

(24) In some sites, the levels of some trace elements (mainly Ba and Mo) were elevated. These cases were associated mainly with on-lease disposal and were, largely, restricted to the 0-15 cm soil layer. In very few cases, the concentration of some trace elements (B, Ni, and Pb) decreased in the treated areas.

(25) All levels of trace elements in the soil found in this study are still within the range reported for normal soils with the exception of Mo. Mo concentration in both the control and treated Kindersley soils was, generally, slightly higher than the Mo concentration range

considered as normal for noncontaminated soils.

### 4.2.2 Crops

(26) In most cases studied, the present drilling waste disposal practices had little effect on crop plant density or plant height.

(27) Grain (or seed) yield was reduced at only one of ten sites investigated, while straw yield was affected at only two sites. Increase in soil salinity appeared to be the main cause for the yield reduction.

(28) The above normal precipitation during the 1986 growing season may have reduced the impact of drilling wastes on soils and crops.

### 4.2.3 Trace Element Uptake by Plants

(29) In general, the crop plants studied do not appear to accumulate trace elements in their tissues. The relatively high soil pH and the possible increase in soil pH resulting from waste application are possible reasons for the low plant uptake of trace elements despite the elevated levels of some trace elements in the soil at a few sites. Also, trace elements undergo complex reations in the soil (e.g. adsorption on soil colloids and precipitation) which may reduce their availability to plants.

(30) Trace elements concentration in the grain and straw was not affected by the present disposal practices, with the exception of few cases. In the latter cases, a decrease or increase in concentration was noted.

### 4.2.4 Grasslands

(31) The only grassland site available for study received excessive

amount of drilling waste. This is estimated to be 1300 to 5000 barrels/acre. The results indicate that spreading of such amounts of drilling wastes on grasslands could result in reduced yield, changes in species composition and elevated levels of trace elements in soils and plants.

# 5 RECOMMENDATIONS

(1) Both growth room and field studies showed that freshwater based drilling wastes applied to agricultural land at a rate of 100 barrels/acre had little or no effect on soil characteristics or plant growth. It is, therefore, recommended that the present off-lease maximum application rate of 100 barrels/acre indicated in the Saskatchewan Approval Guidelines (SEM 1986) be retained.

(2) Based on the growth room study, repeated application or greater spreading rates than stated above may be possible in some cases in the Kindersley region without significant effects on soils and crops. However, this needs to be verified through field experiments such as those proposed by Abouguendia (1985). Long-term effects of greater spreading rates must also be considered.

(3) Because of the strong influence of waste chemical characteristics on plant and soil response to drilling waste application it is recommended that wastes be analyzed for:

- Total dissolved solids (or electrical conductivity).
- Water soluble ions (particularly Na, Cl, $SO_4$).
- pH
- Trace element concentration (particularly B, Cr, Cu, Mo, Ni, and Zn).

(3) The drilling waste criteria established by the Saskatchewan Approval Guidelines (SEM 1986) appeared to be adequate for the protection of soils and crop resources.

(4) The present on-lease disposal practices appear to require some improvements. These should include (a) measures to ensure more uniform spreading of the waste on the lease to avoid the local saline spots, (b)

avoiding land application in the cases of high salinity wastes, (c) reclamation of affected lease sites.

(5) Spreading of drilling wastes on grassland should not be allowed until a maximum allowable rate is established for this type of land cover. This should be bases on both field and laboratory studies.

# 6 LITERATURE CITED

Abouguendia, Z.M. 1985. Potential effects of drilling wastes on crops and soils in Saskatchewan, Proposed Phase II study program. SRC Publication No. E-902-14-F-85.

Abouguendia, Z.M., L. Baschak and R. Godwin. 1985. Potential environmental effects of drilling wastes on crops and soils in Saskatchewan, Phase I: Preliminary Evaluation (2 volumes), SRC Publication No. E-902-11-E-85.

Bear, F.E. 1964. Chemistry of the soil. American Chemical Society, Monograph Series. Reinhold Publishing Corporation.

Chaney, R.L. 1982. Fate of toxic substances in sludge applied to cropland. Proc. Internat. Symp. Land Appl of Sewage Sludge, Oct. 13-15, 1982. Tokyo, Japan.

Dollahite, J.W., L.D. Rowe, L.R. Cook, D. Hightower, E. Bailey and J. Kayzer. 1972. Cooper deficiency and molybdneosis intoxication associated with grazing near a uranium mine. Southwestern Vet. 9:47-50.

Puckett, K.J. and E.J. Finegan. 1980. An analysis of the element content of lichens from the Northwest Territories, Canada. Can. J. Bot. 58:2073-2089.

Saskatchewan Energy and Mines. 1986. Approval guidelines for the on-lease and off-lease land application of freshwater drilling system fluids. Information guideline GL 86-01.

Soil Fertility Committee. 1983. Nutrient requirements guidelines for field crops in Saskatchewan. (Saskatchewan Advisory Council on Soils and Agronomy.)

Wilkinson, L. 1985. SYSTAT - the system for statistics. Systat Inc. Evanston, IL.